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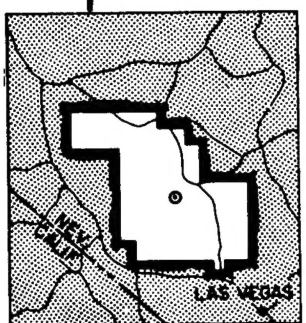


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Project 33.5

## THE INTERNAL ENVIRONMENT OF UNDERGROUND STRUCTURES SUBJECTED TO NUCLEAR BLAST. I. THE OCCURRENCE OF DUST

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CIVIL EFFECTS TEST GROUP

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Operation PLUMBBOB Preliminary Report

Project 33.5

# THE INTERNAL ENVIRONMENT OF UNDERGROUND STRUCTURES SUBJECTED TO NUCLEAR BLAST. I. THE OCCURRENCE OF DUST

By

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Education and Research

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## ABSTRACT

The possible occurrence of dust inside protective shelters as a consequence of nuclear explosions was studied using 18 underground structures subjected to atomic detonations during Operation Plumbbob at distances ranging from 4320 to 840 ft from Ground Zero. The existence of considerable dust was established using sticky-tray fallout collectors. Particulates captured arose from dust on the floor existing preshot, from "dust leaks" in some shelters, and from the internal surfaces of the structures. The latter was established by treating the walls and ceilings of selected shelters with a fluorescent dye solution and subsequently demonstrated fluorescence of captured particles. Data available indicate that the dust-collector technique will be useful in evaluating the environmental aspects of shelters tested in the future and that procedures showing fine spalling may be more sensitive indicators of structural response to dynamic loading than gross spalling. Should this indeed be established, the fluorescent method employed, or an equivalent, will become another simple routine test available to indicate structural response at greater ranges than is now possible without using complicated instrumentation.

## ACKNOWLEDGMENTS

The authors are indebted to many individuals whose cooperation and support made it possible to implement the dust studies which project had its inception in the field. It is with gratitude that we express our thanks to the following individuals:

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CONTENTS


ABSTRACT . . . . . . . . . . . . . . . . . . . . 3
ACKNOWLEDGMENTS . . . . . . . . . . . . . . . . 5

CHAPTER 1 INTRODUCTION. . . . . . . . . . . . 11

CHAPTER 2 METHODS . . . . . . . . . . . . . . 13
2.1 Dust Collectors . . . . . . . . . . . . . . 13
2.1.1 Microscope Slides (Type A Collectors) 13
2.1.2 Sticky-tray Fallout Collectors . . . 13
2.1.3 Air Sampler (Type E Collector). . 14
2.2 Fluorescent-dye Treatment of Shelters . . 15
2.3 Dirt Samples . . . . . . . . . . . . . . . 15
2.4 Structures . . . . . . . . . . . . . . . . 15
2.4.1 Priscilla. . . . . . . . . . . . . . 15
2.4.2 Smoky. . . . . . . . . . . . . . . 21
2.4.3 Galileo . . . . . . . . . . . . . . 21
2.5 Time Dust Collectors Exposed and Recovered 21
2.5.1 Priscilla. . . . . . . . . . . . . . 21
2.5.2 Smoky. . . . . . . . . . . . . . . 36
2.5.3 Galileo . . . . . . . . . . . . . . 36

CHAPTER 3 RESULTS . . . . . . . . . . . . . . 37
3.1 Paired Sticky-paper Collectors (Type B). . 37
3.1.1 Priscilla. . . . . . . . . . . . . . 37
3.1.2 Smoky . . . . . . . . . . . . . . 48
3.1.3 Galileo . . . . . . . . . . . . . . 54
3.2 Single Sticky-paper (Type C) and Sticky-resin (Type D) Collectors. . . . . . . . . 54
3.3 Air Sampler (Type E) Collector. . . . . . 63
3.4 Future Studies . . . . . . . . . . . . . . 63

CHAPTER 4 DISCUSSION . . . . . . . . . . . . 65

CHAPTER 5 SUMMARY . . . . . . . . . . . . . . 68

ILLUSTRATIONS

CHAPTER 2 METHODS . . . . . . . . . . . . . . .
2.1 Plan and Elevation of Typical 3.1 Structures (Priscilla Shot) . . . . . . . . . 16
2.2 Typical Concrete Conduit Section used in the 3.2 Structures (Priscilla Shot) . . . . . . . 17
2.3 Plan and Elevation of 3.3C Structures (Priscilla Shot) . . . . . . . . . . . . . . 18
2.4 Layout of Smoky Shelters. . . . . . . . . . 19
2.5 Diagram of Structure RAa (Smoky) . . . . . 23
2.6 Diagram of Structure CAa (Smoky) . . . . . 24
2.7 Diagram of Structure RAb (Smoky) . . . . . 25
2.8 Diagram of Structure RAc (Smoky) . . . . . 26
2.9 Diagram of Structure CAb (Smoky) . . . . . 27
2.10 Diagram of Structure RAd (Smoky) . . . . . 28
2.11 Diagram of Structure RCa (Smoky) . . . . . 29
2.12 Diagram of Structure RCb (Smoky) . . . . . 30
2.13 Diagram of Structure RCc (Smoky) . . . . . 31
2.14 Diagram of Blast Biology Shelter (Galileo) . . 32

CHAPTER 3 RESULTS . . . . . . . . . . . . . . .
3.1 Type B Dust Collector from Concrete Arch Shelter F3.1-9013.01 (Priscilla) . . . . . . 38
3.2 Type B Dust Collector from Concrete Arch Shelter F3.1-9014.02 (Priscilla) . . . . . . 39
3.3 Type B Dust Collector from Concrete Arch Shelter F3.1-9014.03 (Priscilla) .. . . . . . 40
3.4 Type B Dust Collector from Concrete Arch Shelter F3.1-9015 (Priscilla) . . . .. . . . 41
3.5 Type B Dust Collector from Concrete Circular Shelter F3.2-9017.01 (Priscilla). . . . 43
3.6 Type B Dust Collector from Concrete Circular Shelter F3.2-9017.02 (Priscilla). . . . 44
3.7 Type B. Dust Collector from Concrete Circular Shelter F3,2-9017.03 (Priscilla). . . . 45
3.8 Type B Dust Collector (right side) from Steel Arch Shelter F3.3C-9019.02 (Priscilla) . . . 46
3.9 Type B Dust Collector (left side) from Steel Arch Shelter F3.3C-9019.02 (Priscilla) . . . 47
3.10 Type B Experimental Dust Collector from Rectangular Structure RAa (8-30.7-8008) (Smoky) . . . . . . . . . . . . . . . . . . 49
3.11 Type B Experimental Dust Collector from Rectangular Structure RAb (8-30.7-8010) (Smoky) . . . . . . . . . . . . . . . . . . 50
3.12 Type B Experimental Dust Collector from Rectangular Structure RAc (8-30.7-8011) (Smoky) . . . . . . . . . . . . . . . . . 51

ILLUSTRATIONS (Continued)


3.13 Type B Experimental Dust Collector From Rectangular Structure RAd (8-30.7-8013) (Smoky) . . . . . . . . . . . . . . . . . 52
3.14 Paired Sticky Paper Laboratory Control. . 53
3.15 Type B Experimental Dust Collector from Rectangular Structure RCa (8-30.7-8014) (Smoky) . . . . . . . . . . . . . . . . . 55
3.16 Type B Experimental Dust Collector from Rectangular Structure RCb (8-30.7-8015) (Smoky) . . . . . . . . . . . . . . . . . 56
3.17 Type B Experimental Dust Collector from Rectangular Structure RCc (8-30.7-8016) (Smoky) . . . . . . . . . . . . . . . . . 57
3.18 Type B Experimental Dust Collector from Circular Structure CAa (8-30.7-8009) (Smoky) . . . . . . . . . . . . . . . . 58
3.19 Type B Experimental Dust Collector from Circular Structure CAb (8-30.7-8012) (Smoky) . . . . . . . . . . . . . . . . . . . 59
3.20 Type B Dust Collector used as a "Dirty" Control in Rectangular Structure RCc (8-30.7-8016) (Smoky) . . . . . . . . . 60
3.21 Type B Dust Collector used as a "Clean" Control in Rectangular Structure RCc (8-30.7-8016) (Smoky) . . . . . . . . . 61
3.22 Type B Experimental Dust Collector from the Slow- and Fast-fill Sides of Structure 1-33.1-8002 (Galileo) . . . . . . . . . 62


TABLES


CHAPTER 2 METHODS . . . . . . . . . . . . . .
2.1 Priscilla Structures in Which Dust Collectors were Located . . . . . . . . . 20
2.2 Smoky Structures in Which Dust Collectors were Located . . . . . . . . . 22
2.3 Time Priscilla Dust Collectors Exposed and Recovered . . . . . . . . . . . . . 33
2.4 Time Smoky and Galileo Dust Collectors Exposed and Recovered . . . . . . . . 34

Chapter 1

## INTRODUCTION

In 1950 Desaga[1] described fatalities from the inhalation of dust among individuals who had entered structures to escape the effects of aerial bombardment. The sources of the dust, which often was in the particle-size range to mechanically occlude the respiratory passages, was from collapsed buildings and from the ceilings and walls of structures near which bomb detonations occurred. Explosions can cause dust inside nonpenetrated shelters by a variety of mechanical factors including the "spalling effect", a phenomenon which involves the transmission of a shock or pressure pulse through the walls of a structure, which, upon reaching the air-structure interface at the inner surface, is reflected as a tension wave back into the wall. The consequence of the reflection is the spalling of portions of the wall and/or fine particles of different sizes which are "kicked" off the inner surface into the internal atmosphere. The existence of a potential hazard to personnel from inhaled particulates is a function of the character of the inhaled material, the particle size, concentration in the inhaled gas, and the total time of exposure. Even if the dust were not sufficient in concentration nor of the appropriate size to produce fatality, dusty atmospheres are annoying and through irritation of the respiratory airways can be a factor in increasing the incidence of infections of the paranasal sinuses, the bronchi, and the lungs.

Because dust is a known environmental hazard and because no data exist which are applicable to underground structures exposed to nuclear detonations, a decision was made in the field to do a pilot study of selected underground shelters which were to be tested during Operation Plumbbob. Work feasible was limited somewhat by late initiation of the study and by the requirements of structural and instrumentation projects already underway. However, it was possible to arrange the use of 18 underground shelters (eight in the Priscilla shot, nine in the Smoky shot, and one in the Galileo shot). The purposes of the study were to (a) obtain samples of postshot dust

appearing in structures as a consequence of nuclear explosions, (b) establish, if possible, the sources of postshot dust, e. g., whether or not particles arose from preexisting dirt on the floor or actually spalled from the ceiling, walls, and floor as a result of the explosion, and (c) establish the particle sizes of pre- and postshot dust.

## REFERENCE


1. Hans Desaga, Experimental Investigations of the Action of Dust, Chap. XIII-B, pp. 1188-1203, "German Aviation Medicine World War II," U. S. Government Printing Office, Washington, D. C., 1950.

Chapter 2

# METHODS

## 2.1 DUST COLLECTORS

Three types of dust collectors were utilized; namely, microscope slides, "sticky-tray" fallout collectors, and a motor-driven air sampler.

### 2.1.1 Microscope Slides (Type A Collectors)

A 1-in.-square piece of scotch tape, sticky side up, was fixed to microscope slides. These were taped to the floors of eight Priscilla structures preshot. When the slides were recovered postshot, the entire top of the slide was covered with scotch tape, sticky side down.

### 2.1.2 Sticky-tray Fallout Collectors

Two types of sticky-tray collectors were employed. The first used sticky paper, the second was covered with sticky resin.

(a) Sticky-paper Trays (Type B and C Collectors). The sticky-paper trays were obtained through the courtesy of K. H. Larsen, Director, Program 37, Civil Effects Test Group; they had been used as fallout collectors during several operations by the University of California at Los Angeles group. Transparent sticky paper was fixed with masking tape to the top of either aluminum trays (12 in. x 12 in.) or 1/16-in.-thick plates of galvanized sheet metal (9.5 in. x 10.5 in.). The top of the sticky paper (8 in. x 9 in.) was protected by two rectangular pieces of paper each covering half the sticky surface. At the time exposure of the tray was desired, one had only to strip off the paper protector.

Installation was simply accomplished by cementing the trays

to the floor of each structure, except in one instance in which the trays were taped to benches.

In the eight Priscilla shelters one of the papers protecting the sticky paper was removed from each plate (two of which were located in each structure) immediately following installation, i.e., four days before the shot (D-4). The uncovered side was marked "C" for control. Upon button-up, the other protective paper was removed, thus exposing the other side of the collector, which was marked "E" for experimental. With this arrangement the control side of the fallout collector collected pre- and postshot dust, and the experimental side collected predominantly postshot material. Upon recovery the trays in each shelter were placed face to face, care being taken to oppose the control side of one collector to the control side of the other.

Two, sometimes four, sticky-paper trays were placed in the nine Smoky shelters for preshot controls. They were removed before button-up and placed sticky face to sticky face to trap the collected dust between two layers of transparent material.

Two experimental trays were installed in each Smoky shelter and one in each of the two compartments of the Galileo shelter. These were uncovered at button-up, and, upon recovery, were paired as noted above, except for the Galileo case in which each of the two transparent papers was cut in half and paired, thus giving a half-size preparation. Such paired sticky-paper trays are referred to later as type B collectors.

In the Smoky shelters, which were treated with fluorescent dye as will be noted later, single sticky-paper trays were installed and uncovered at button-up. When recovered, another dummy aluminum tray was taped over the tray for protection. These single trays are later referred to as type C collectors.

(b). Sticky-resin Trays (Type D Collectors). Sticky-resin trays (type D), information about which was kindly supplied by Fred G. Hirsch, were prepared by coating one side of the aluminum trays with an alkyl resin put in a solution of toluene (1 part resin to 4 parts toluene). The coating operation was done using an atomizer commonly employed to spray the nasal and pharyngeal passages. Dummy trays were taped over the resin collectors to protect them during transport and installation. Single resin trays were installed in the fluorescent dye-treated Smoky structures, uncovered near button-up, and protected on recovery by replacing the dummy tray.

### 2.1.3 Air Sampler (Type E Collector)

Two high-volume air samplers (UCLA type), obtained from Program 37 through the cooperation of K. H. Larsen, and a power generator, obtained from the Department of Defense, were installed

in one of the Smoky structures in an attempt to obtain dust samples as a function of time and to improve data in the small particle-size range.

## 2.2 FLUORESCENT-DYE TREATMENT OF SHELTERS

To aid in establishing the source of postshot dust, walls and ceilings of four Smoky shelters were treated with fluorescent dye. A 0.1 per cent solution of Fluorescein Sodium* (Matheson Coleman and Bell, Inc., East Rutherford, N. J.) was placed in a 50/50 water-alcohol (Reagent Alcohol, Scientific Products Division, American Hospital Supply Corporation, Evanston, Ill.) solution, due care being taken to avoid toxic and explosive hazards. The solution was applied using ordinary paint rollers in structures RAa, CAb, RAd, and RCb (see Fig. 2.4). Floors of the structures were covered to avoid contamination of floor dirt with the dye, a precaution to ensure that any fluorescent particles collected on the experimental trays arose from spalling rather than from floor dirt.

## 2.3 DIRT SAMPLES

At the time the dust collectors (control or experimental) were placed, a sample of dirt was scraped from the floor of each structure and placed in a marked bottle. These samples were for use in establishing the character of shelter dirt existing preshot.

## 2.4 STRUCTURES

### 2.4.1 Priscilla

Through the courtesy of DOD, eight structures to be tested with hatches and ventilating ducts closed were made available for the dust study. The structures were of the type shown in Figs. 2.1, 2.2, and 2.3. Table 2.1 identifies the structures by number, shows their distance from Ground Zero (GZ), the type of each, and gives the number and type of collectors installed in each structure, along with their location. Also, the wall thicknesses and depths of earth cover for the shelters are noted.

---

*The authors are indebted to T. L. Chiffelle and Frederic G. Hirsch who carried out preliminary laboratory investigations to establish the feasibility of the method of "marking" concrete with dye, the dye to use, and the techniques required for treating dye particles to restore fluorescence which is quenched by some little-understood interaction with concrete.

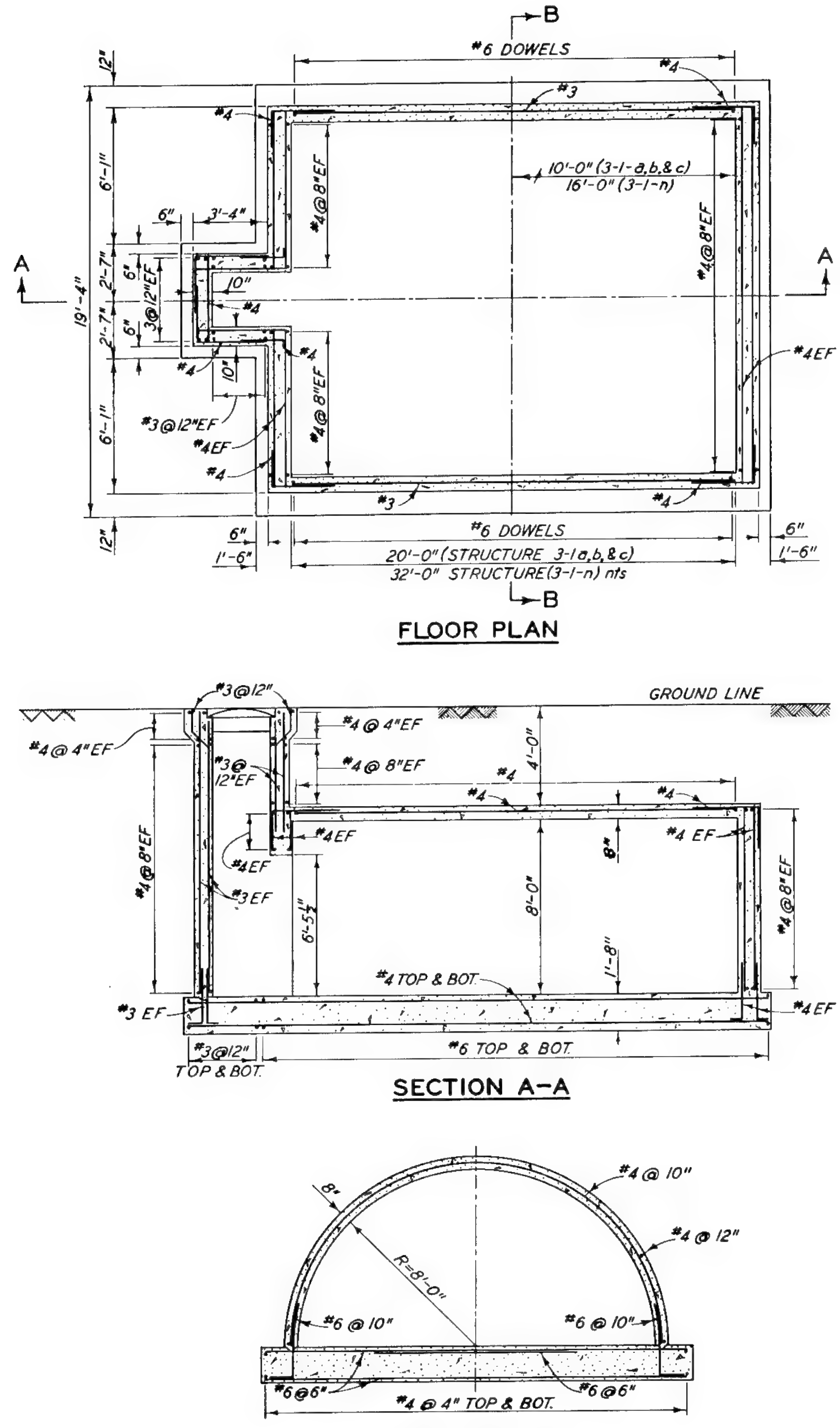


Fig. 2.1—Plan and elevation of typical 3.1 structures (Priscilla Shot).

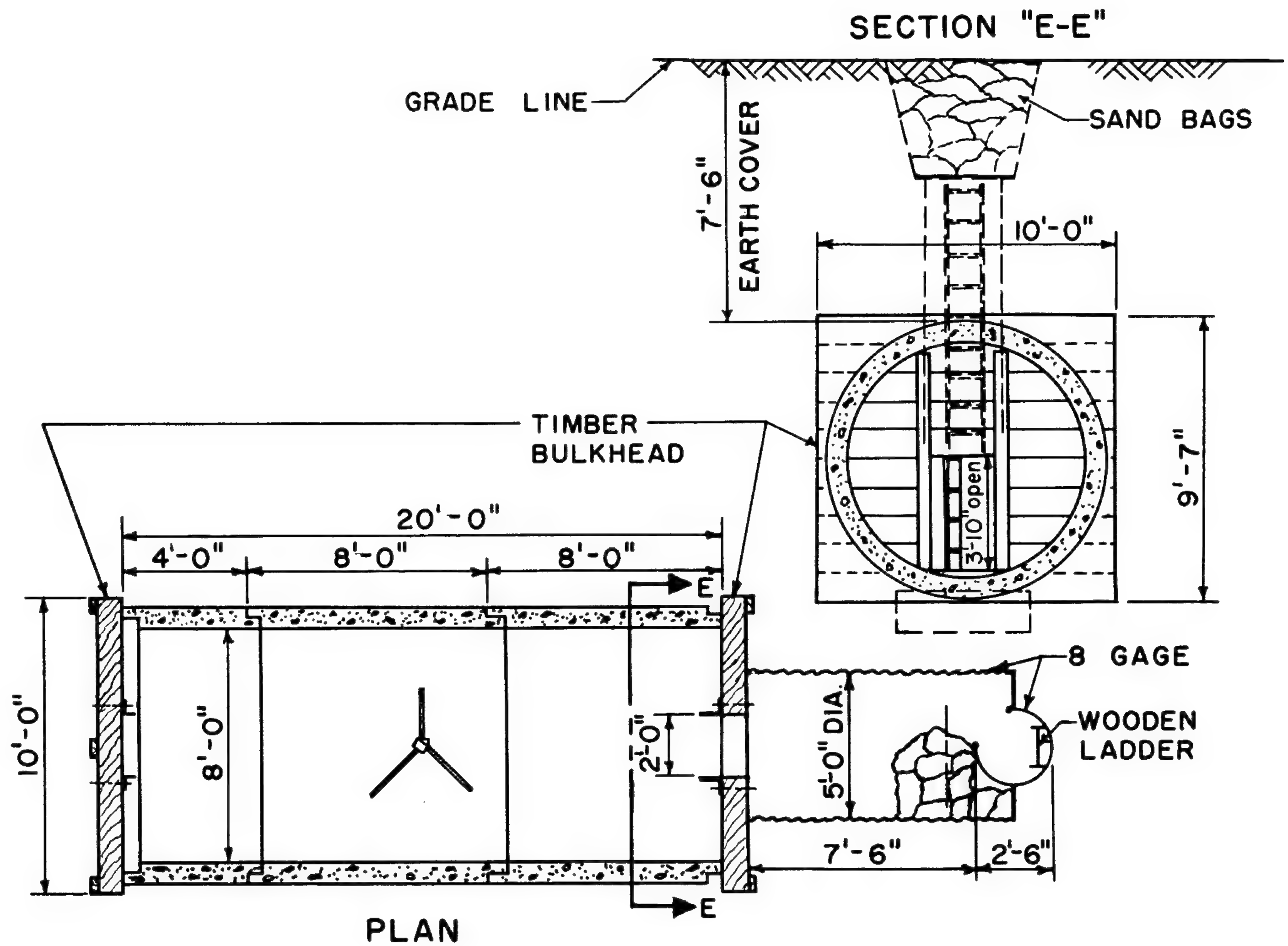


Fig. 2.2—Typical concrete conduit sections used in the 3.2 structures (Priscilla Shot).

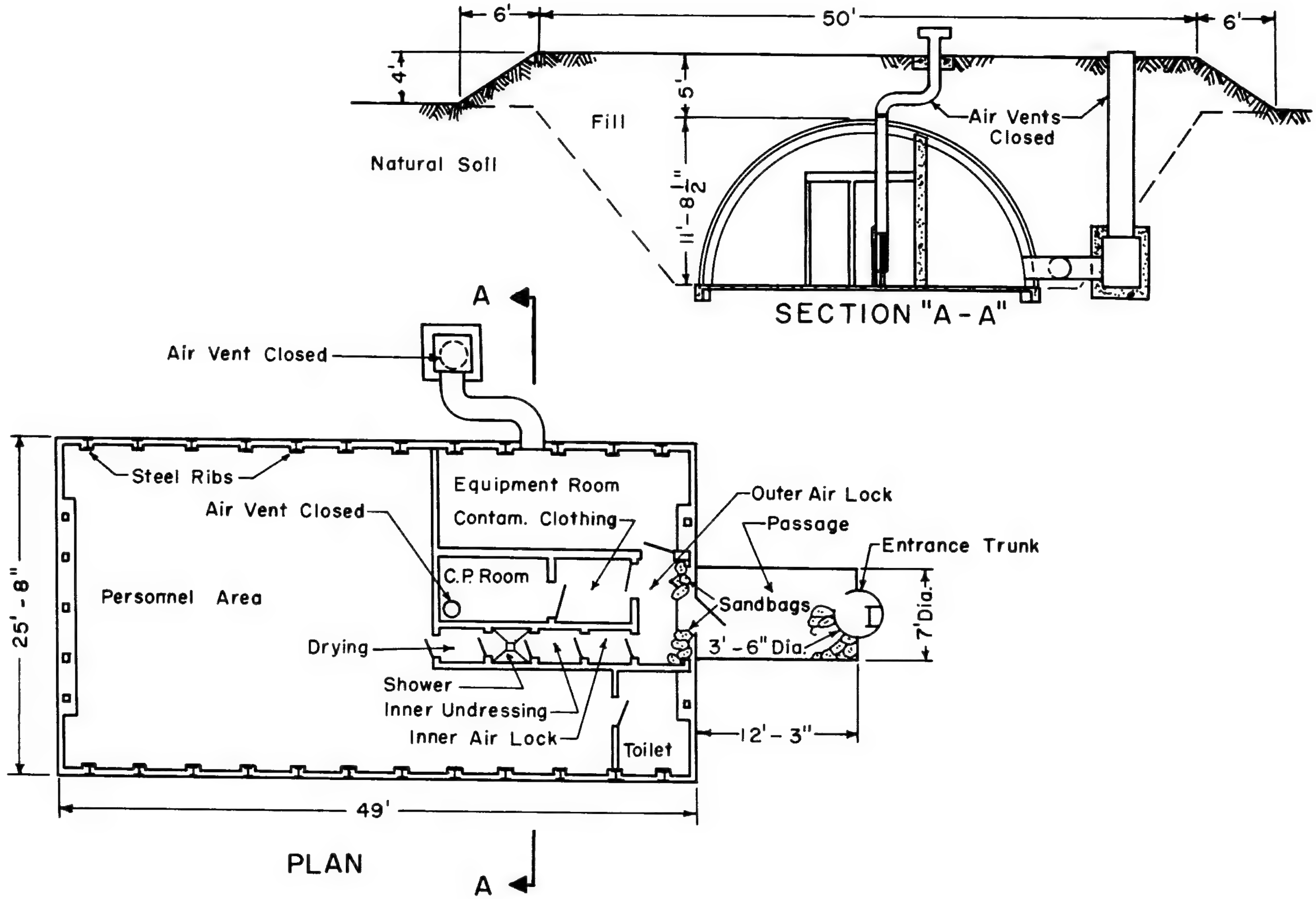


Fig. 2.3— Plan and elevation of 3.3C structures (Priscilla Shot).

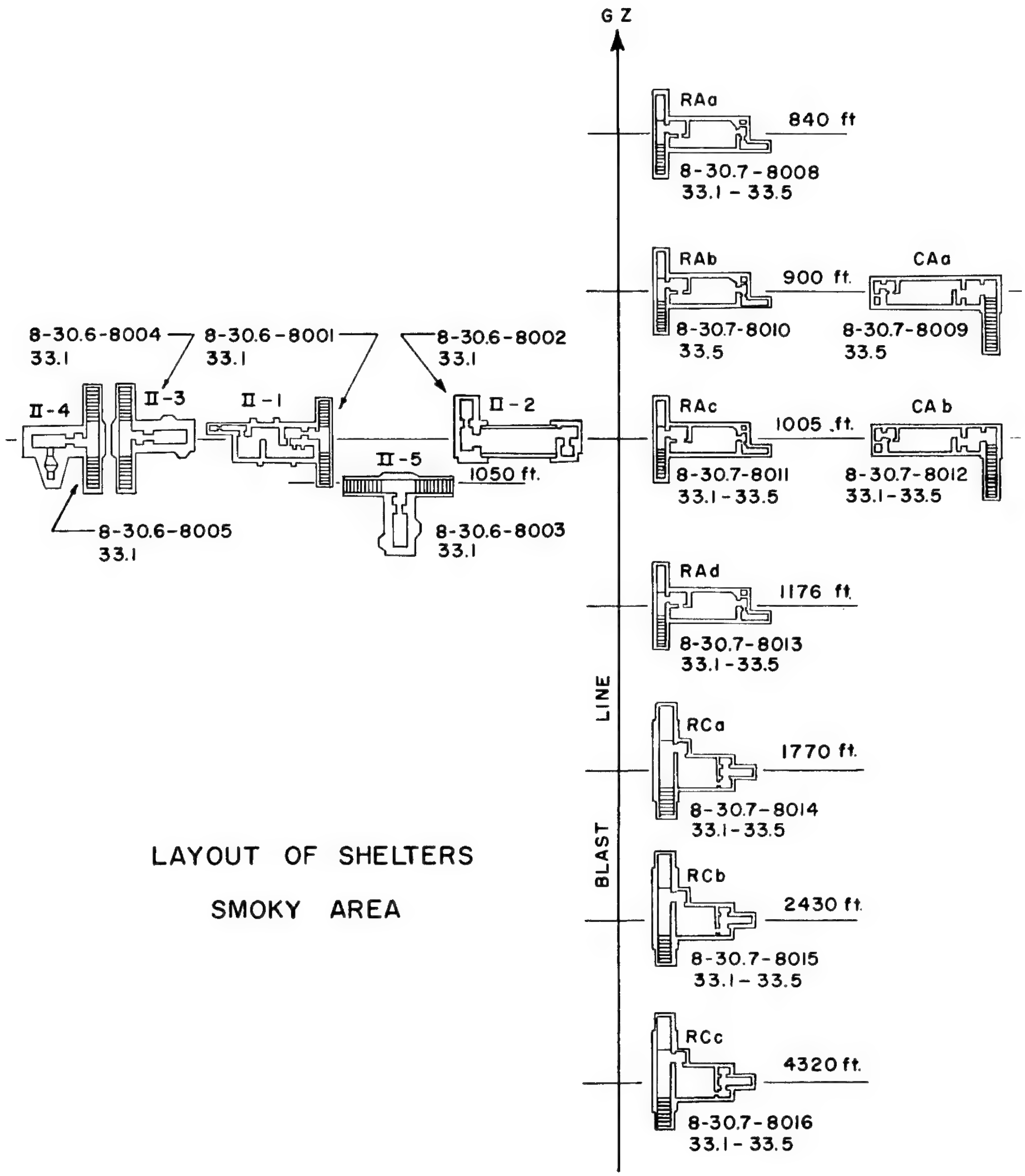


Fig. 2.4—Layout of Smoky shelters.

Table 2.1—PRISCILLA STRUCTURES IN WHICH DUST COLLECTORS WERE LOCATED

| Structure No. | Distance from GZ, ft | Type structure | Ceiling and wall thickness, in. | Earth cover, ft | Number type A collector | Number type B collector | Location |
|---|---|---|---|---|---|---|---|
| F3.1-9014.01 | 860 | Concrete arch | 8 | 4 | 41a<br>41b | 3.1-1A<br>3.1-1B | Near center<br>Near end |
| F3.1-9014.02 | 1040 | Concrete arch | 8 | 4 | 42a<br>42b | 3.1-2A<br>3.1-2B | Near center<br>Near end |
| F3.1-9014.03 | 1360 | Concrete arch | 8 | 4 | 43a<br>43b | 3.1-2A<br>3.1-2B | Near center<br>Near end |
| F3.1-9015 | 1360 | Concrete arch | 8 | 4 | 15a<br>15b | 3.1-5A<br>3.1-5B | Near center<br>Near end |
| F3.2-9017.01 | 1040 | Concrete and steel conduit, mortar joints, wooden end bulkhead | 8.5 | 7.5 | E-a<br>E-b | 3.2-1A<br>3.2-1B | Near center<br>Near end |
| F3.2-9017.02 | 1150 | Concrete and steel conduit, mortar joints, wooden end bulkhead | 8.5 | 7.5 | J-a<br>J-b | 3.2-2A<br>3.2-2B | Near center<br>Near end |
| F3.2-9017.03 | 1360 | Concrete and steel conduit, mortar joints, wooden end bulkhead | 8.5 | 7.5 | L-a<br>L-b | 3.2-3A<br>3.2-3B | Near center<br>Near end |
| F3.3C-9019.02 | 1360 | Steel arch on concrete slab | -- | 5.0 | 92a<br>92b<br>92c<br>92d | 3.3A<br>3.3B<br>3.3C<br>3.3D | Near center rt.<br>Near end right<br>Near end left<br>Near center left |

### 2.4.2 Smoky

Access to underground shelters scheduled for test with doors and hatches closed and ventilation systems protected by sand filters on the intake side was arranged through the cooperation of the Federal Civil Defense Administration. The structures used were all those located to the right of the blast line noted in Fig. 2.4, which depicts the general layout of the Smoky structures and shows the distance of each from GZ. Table 2.2 tabulates the Smoky shelters, their type and wall thickness, the amount of earth cover, and the number and type of experimental and control dust collectors located in each. In addition, the dye-treated structures are set forth along with those in which vacuum cleaning was feasible and accomplished before button-up.

The locations of the several types of experimental dust collectors are shown diagrammatically in Figs. 2.5 through 2.13, along with shelter dimensions and other relevant data.

### 2.4.3 Galileo

One underground shelter (Station 1-33.1-8002) containing two rooms located 1050 ft from GZ was tested "open," i.e., the fast-fill side was allowed to fill with gas through the main entry ramp and blast winds entered the slow-fill chamber through a circular orifice 3 ft in diameter covered with a 1/2-in. steel plate containing a number of holes 1/4 in. in diameter. One type B dust collector was placed in the fast- and slow-fill sides of the shelter, as shown in Fig. 2.14.

## 2.5 TIME DUST COLLECTORS EXPOSED AND RECOVERED

### 2.5.1 Priscilla

Microscope slides and paired sticky tray dust collectors were placed and the experimental halves of the trays were exposed in the eight Priscilla underground structures four days before the shot (D-4). The structures were fairly clean on D-4, but prior to button-up they were swept with sweeping compound. Thus, the preshot dirt trapped on the trays was that stirred up during cleaning and by personnel working in the shelters.

Button-up was accomplished on either D-2 or D-3 by DOD personnel, who at that time uncovered the experimental sides of the trays; they recovered the type A and type B collectors on D+3, D+4, and D+8 days, as shown in Table 2.3.

Table 2.2—SMOKY STRUCTURES IN WHICH DUST COLLECTIONS WERE LOCATED
(See Fig. 2.4 for Structure Numbers)

| Structure designation | Distance from GZ, ft | Type structure | Earth cover | Ceiling and wall thickness | No. and type exper. collectors* B | C | D | E | No. and type control collectors (B)** | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| RAa<br>8-30.7-8008 | 840 | Concrete rec.<br>steel doors | 4' | 1'11-1/2" | 2 | 1 | 1 | | 1 (C) | Dye treated D-11 |
| CAa<br>8-30.7-8009 | 900 | Concrete circ.<br>steel doors | 5'3" | 1'3-3/4" | 2 | | | | 1 (C) | |
| RAb<br>8-30.7-8010 | 900 | Concrete rec.<br>steel doors | 4' | 1'11-1/2" | 2 | | | | 1 (C) | |
| RAc<br>8-30.7-8011 | 1005 | Concrete rec.<br>steel doors | 4' | 1'11-1/2" | 2 | | | | 1 (C)<br>1 (C) | |
| CAb<br>8-30.7-8012 | 1005 | Concrete circ.<br>steel doors | 5'3" | 1'11-1/2" | 2 | 1 | 1 | 2 | 1 (C) | Dye treated D-11<br>vacuum cleaned D-1 |
| RAd<br>8-30.7-8013 | 1176 | Concrete rec.<br>steel doors | 4' | 1'11-1/2" | 2 | 1 | 1 | | 1 (C) | Dye treated D-11<br>vacuum cleaned D-1 |
| RCa<br>8-30.7-8014 | 1770 | Concrete rec.<br>steel doors | 3' | 11-3/4" | 2 | | | | 1 (C)<br>1 (C') | |
| RCb<br>8-30.7-8015 | 2430 | Concrete rec.<br>steel doors | 3' | 11-3/4" | 2 | 1 | 1 | | 1 (C) | Dye treated D-11<br>vacuum cleaned D-2 |
| RCc<br>8-30.7-8016 | 4320 | Concrete rec.<br>steel doors | 3' | 11-3/4" | 2 | | | | 1 (C)<br>1 (C') | Vacuum D-1 |
| Totals | | | | | 18 | 4 | 4 | 2 | 12 | |

*Type collectors: B, sticky paper, paired. C, sticky paper, single. D, sticky-resin, single. E, air sampler.

**Control type B collectors (C), dirty control. (C'), clean control.

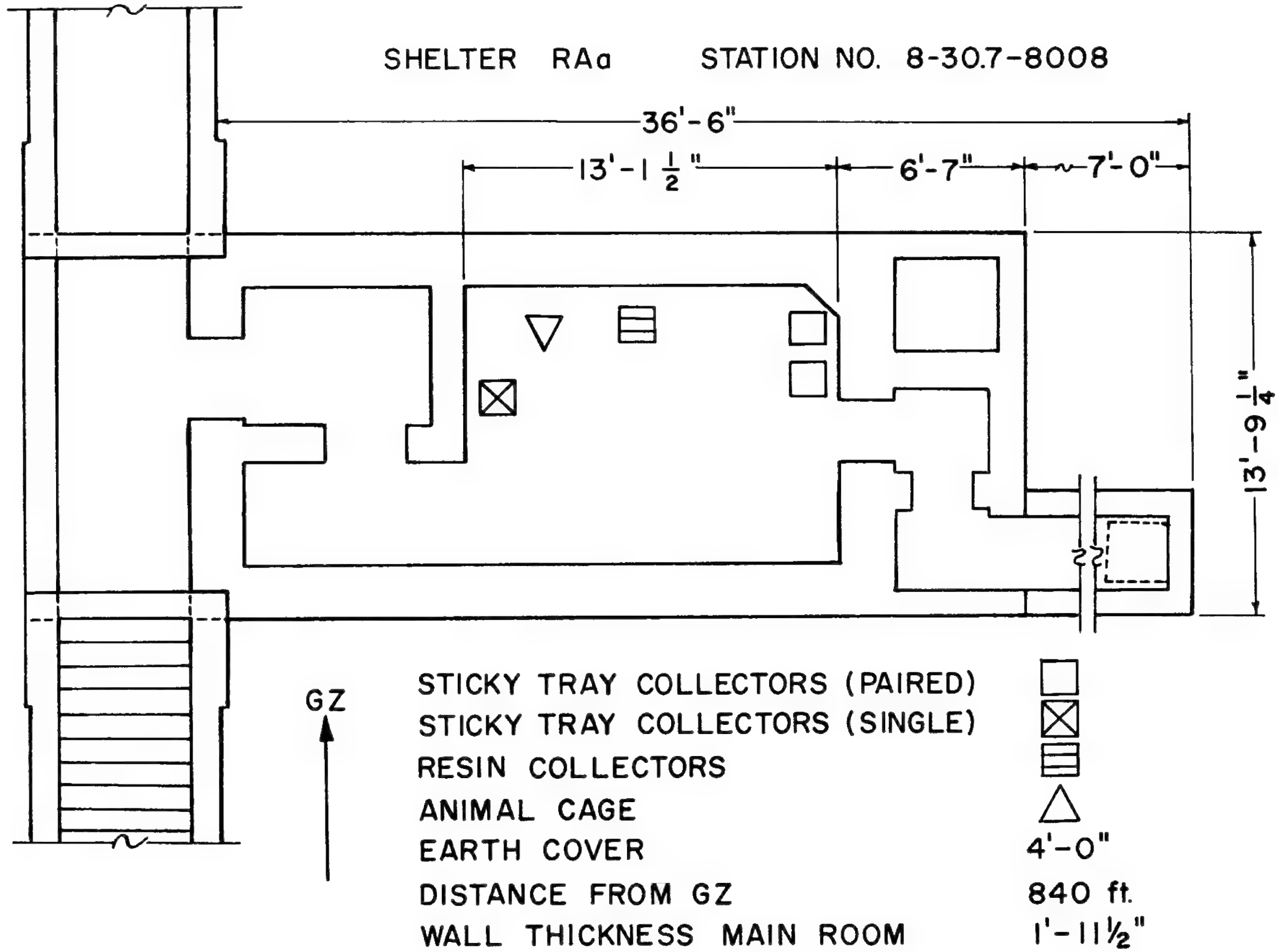


Fig. 2.5—Diagram of structure RAa (Smoky).

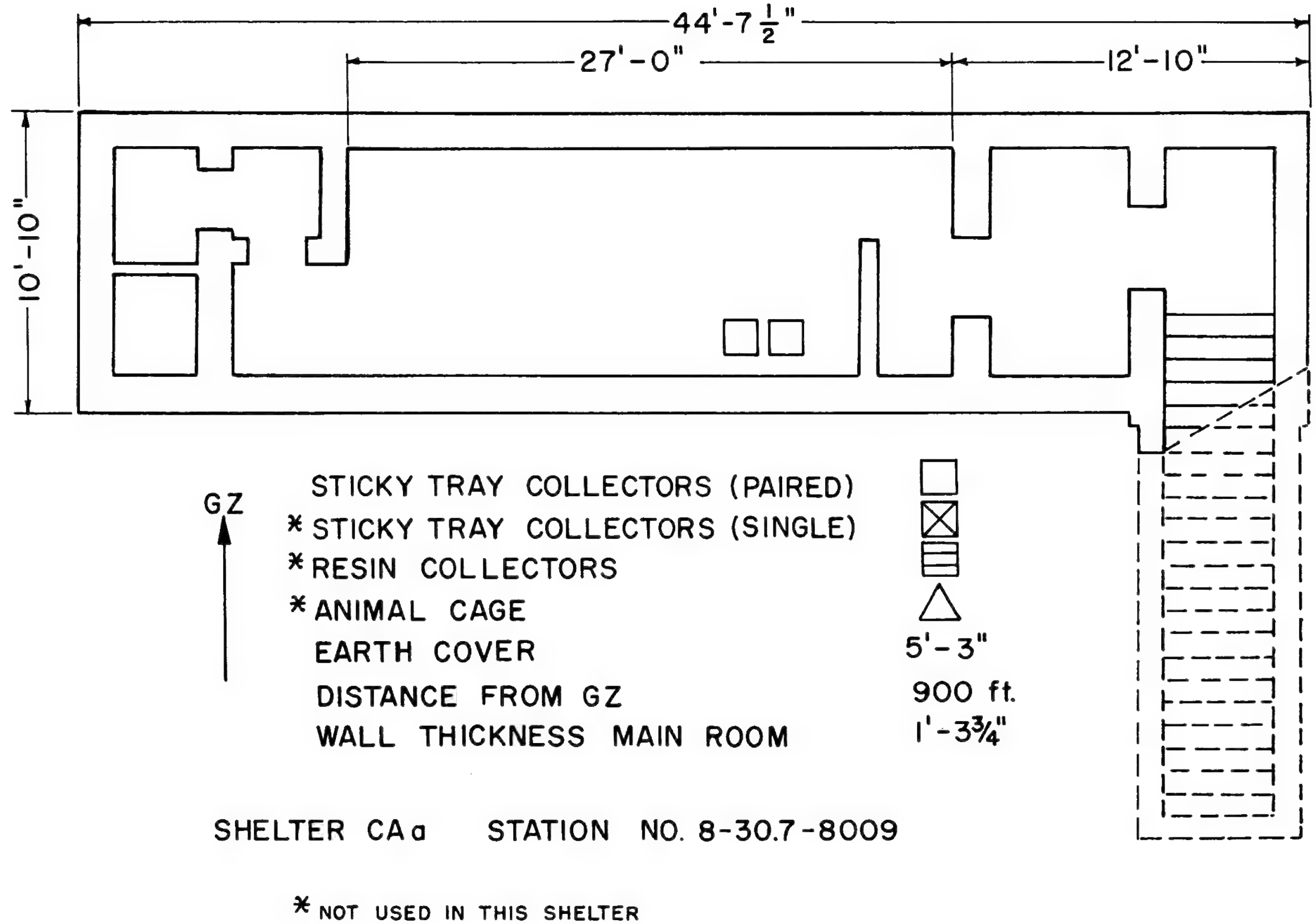


Fig. 2.6—Diagram of structure CAa (Smoky).

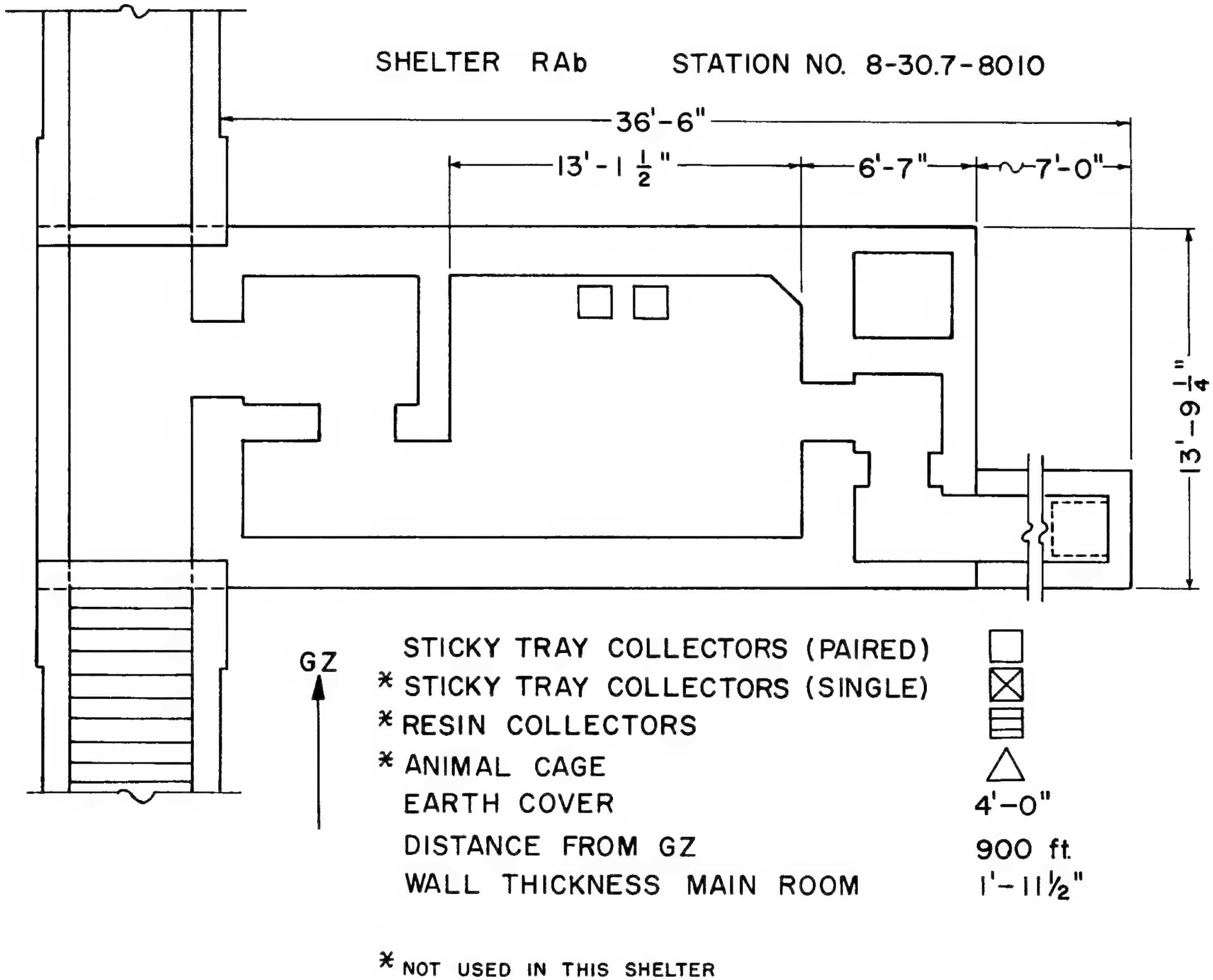


Fig. 2.7—Diagram of structure RAb (Smoky)

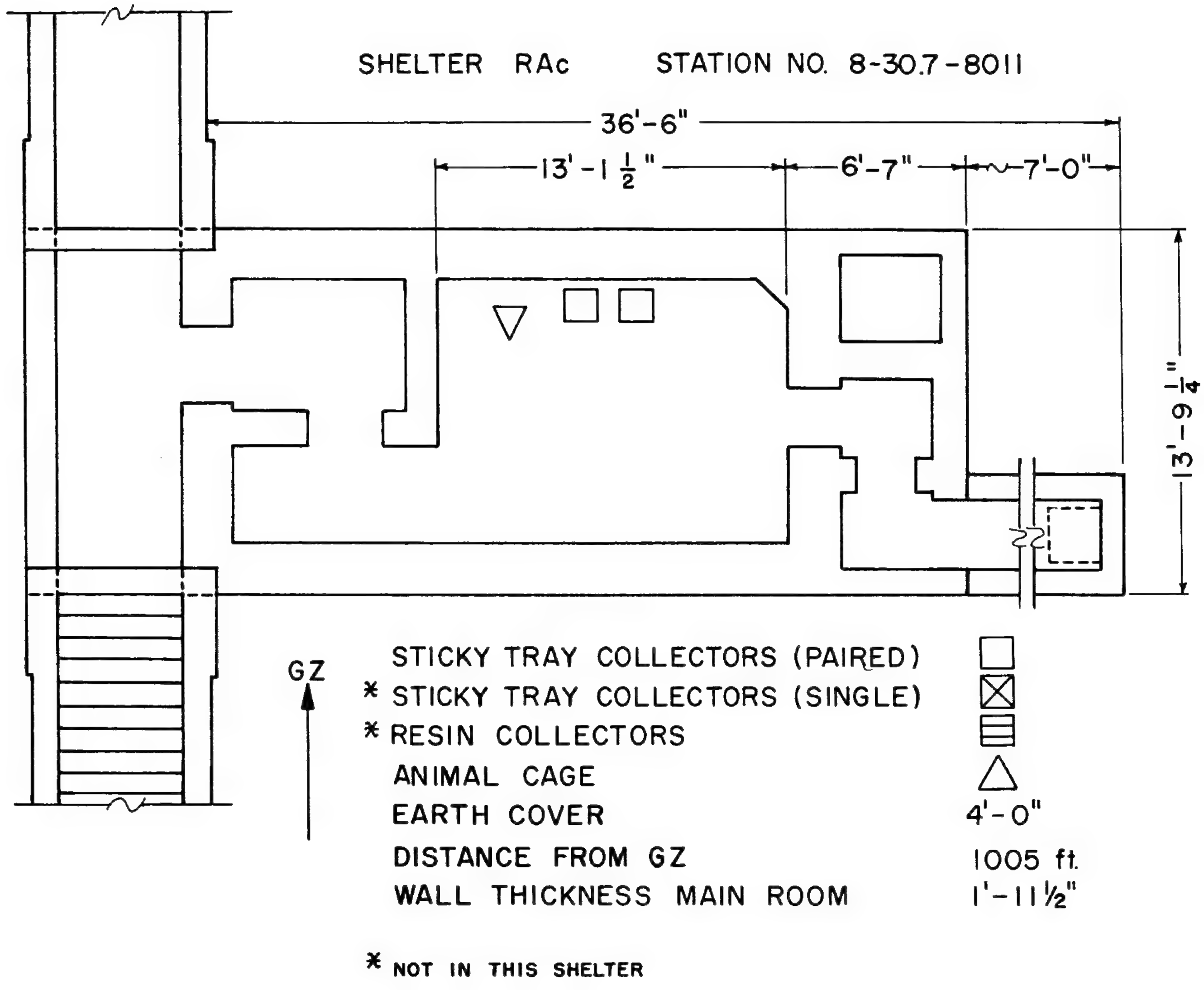


Fig. 2.8—Diagram of structure RAc (Smoky)

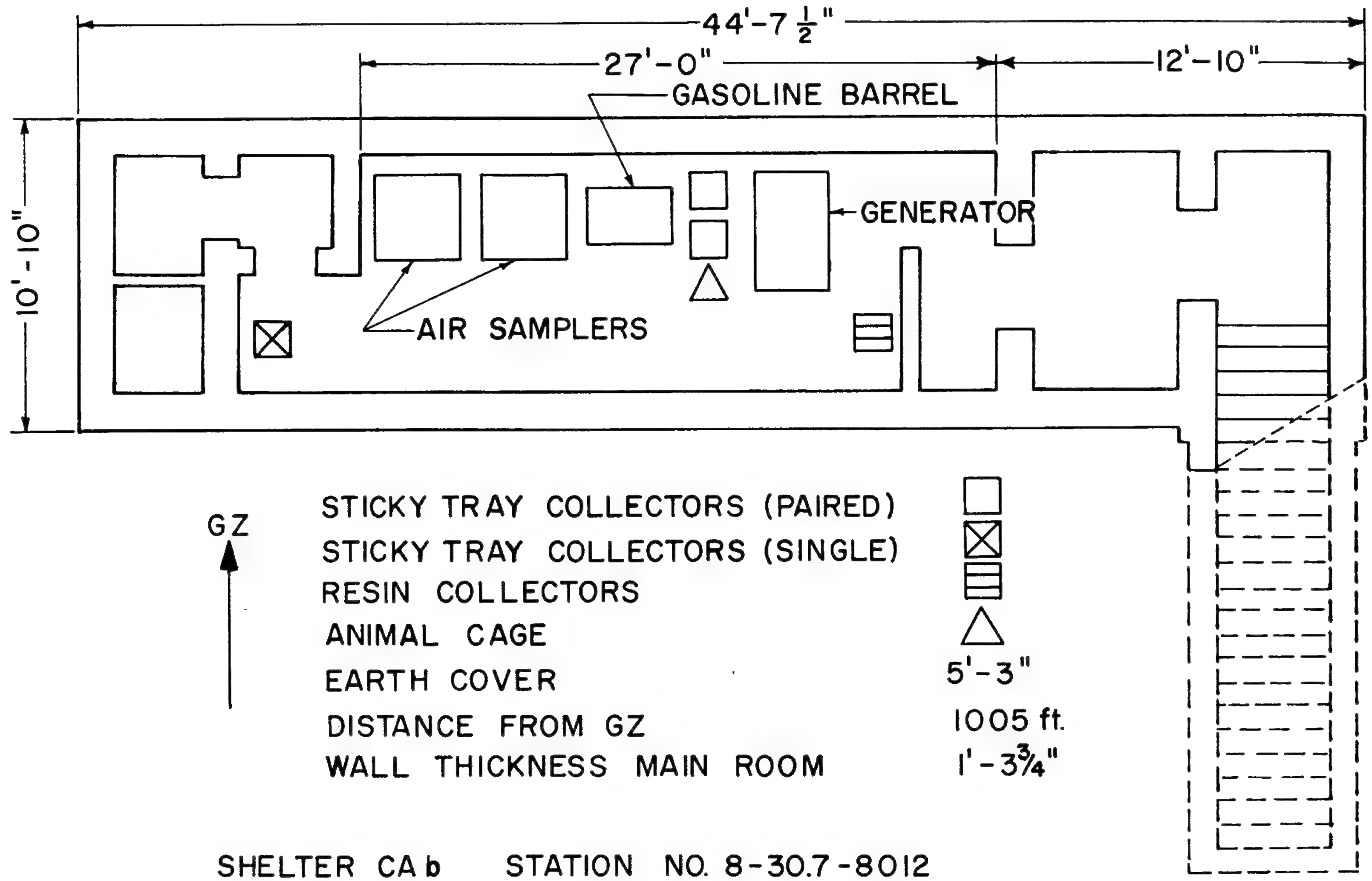


Fig. 2. 9—Diagram of structure CAb (Smoky)

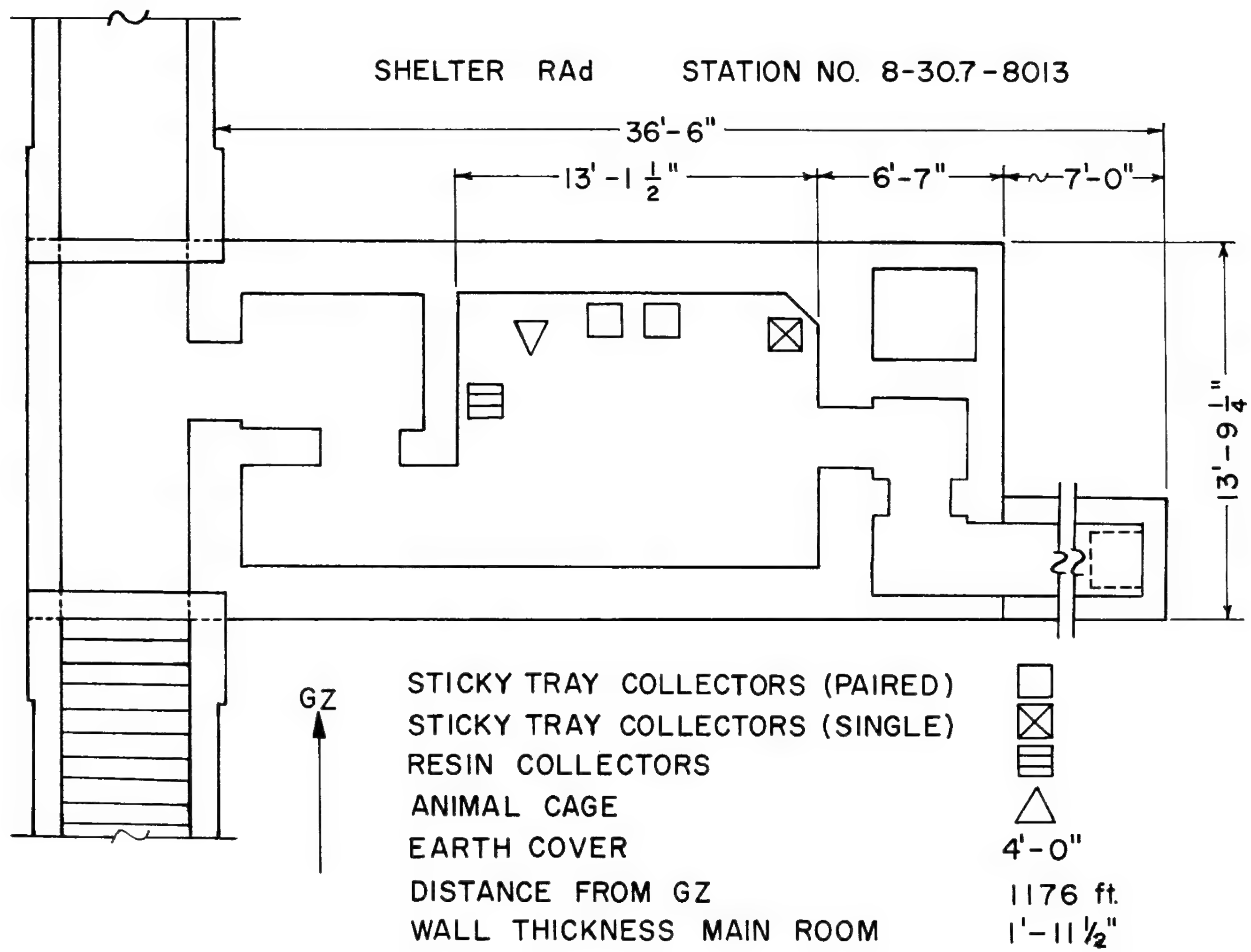


Fig. 2.10—Diagram of structure RAd (Smoky).

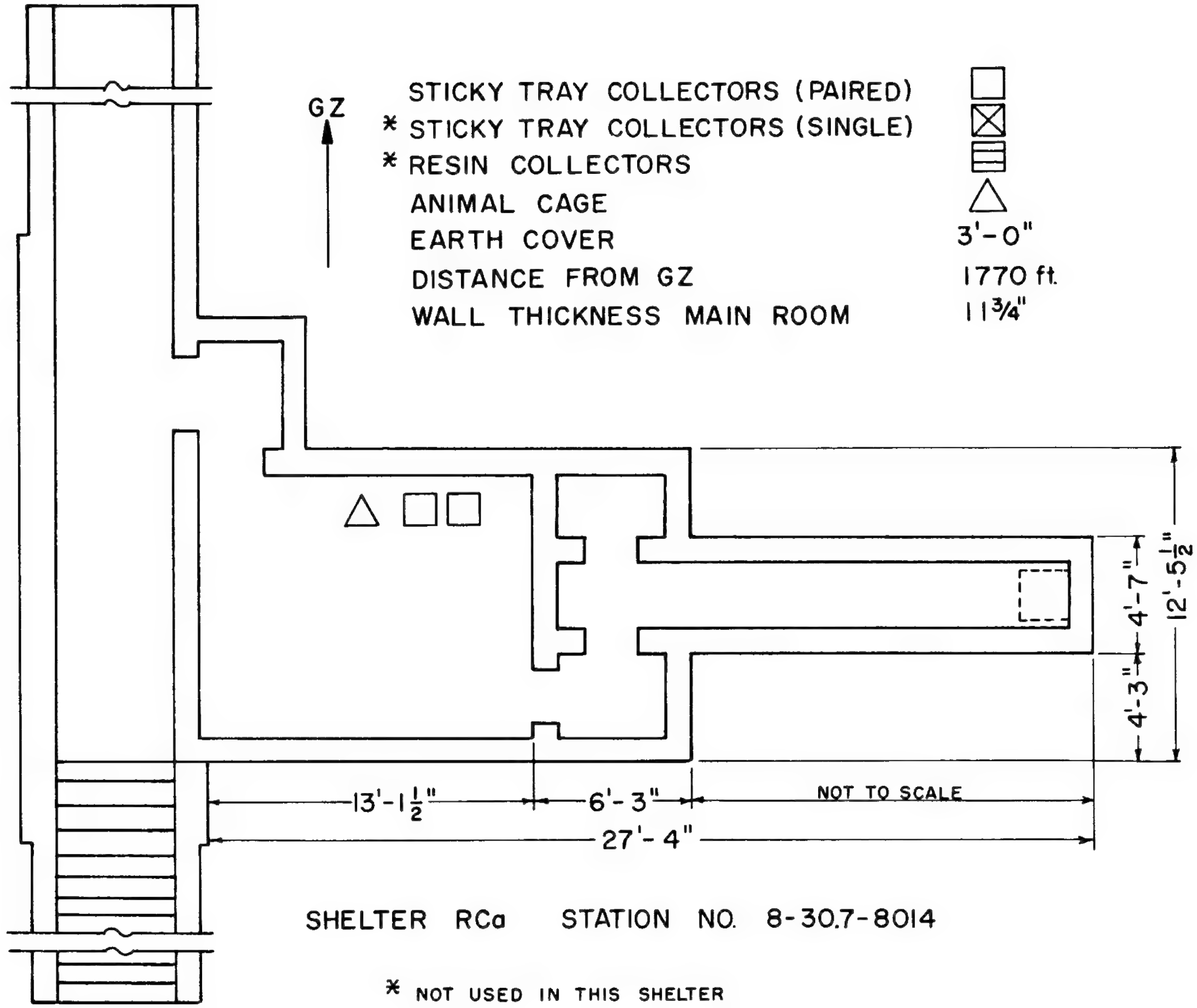


Fig. 2. 11—Diagram of structure RCa (Smoky).

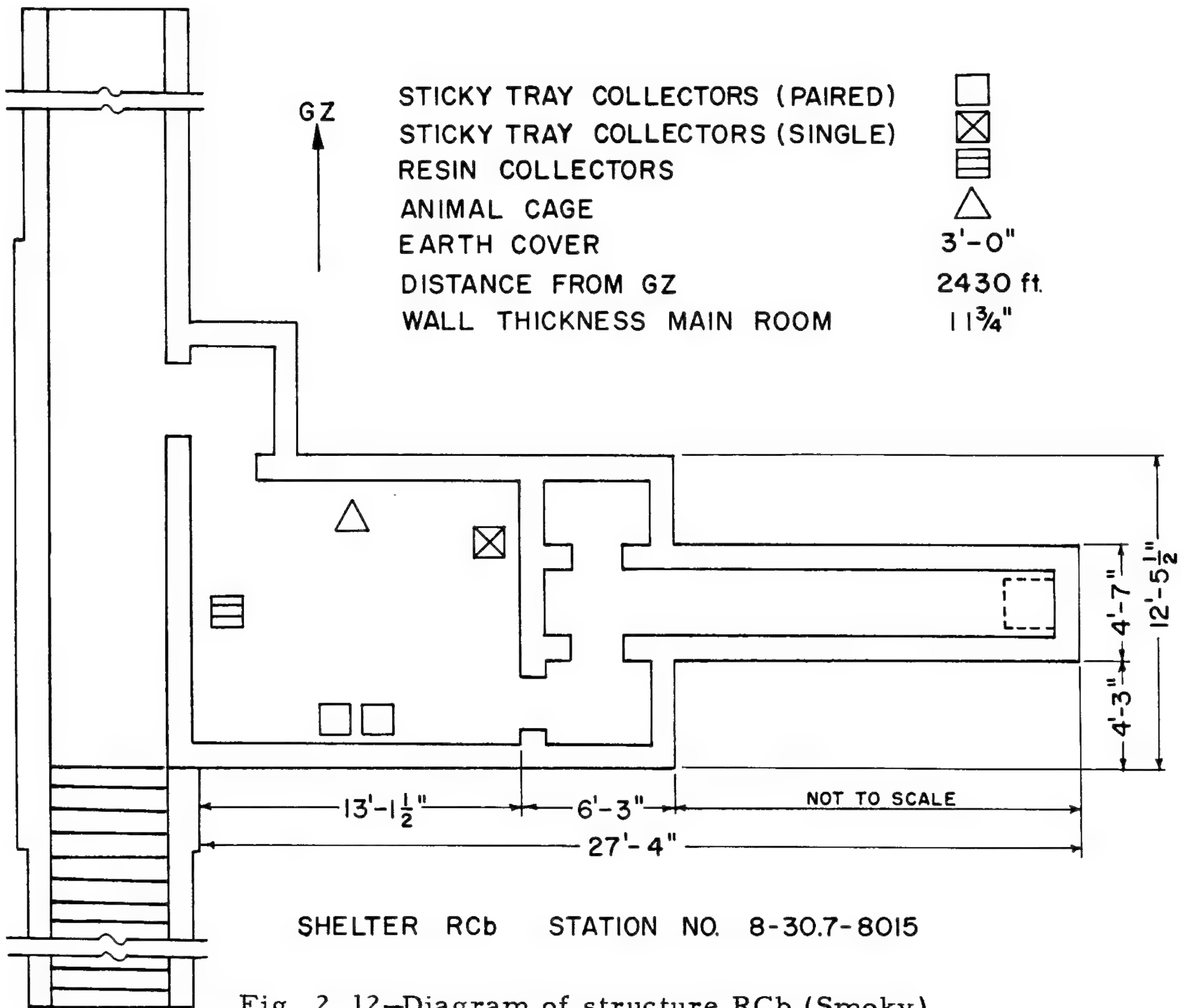


Fig. 2. 12—Diagram of structure RCb (Smoky).

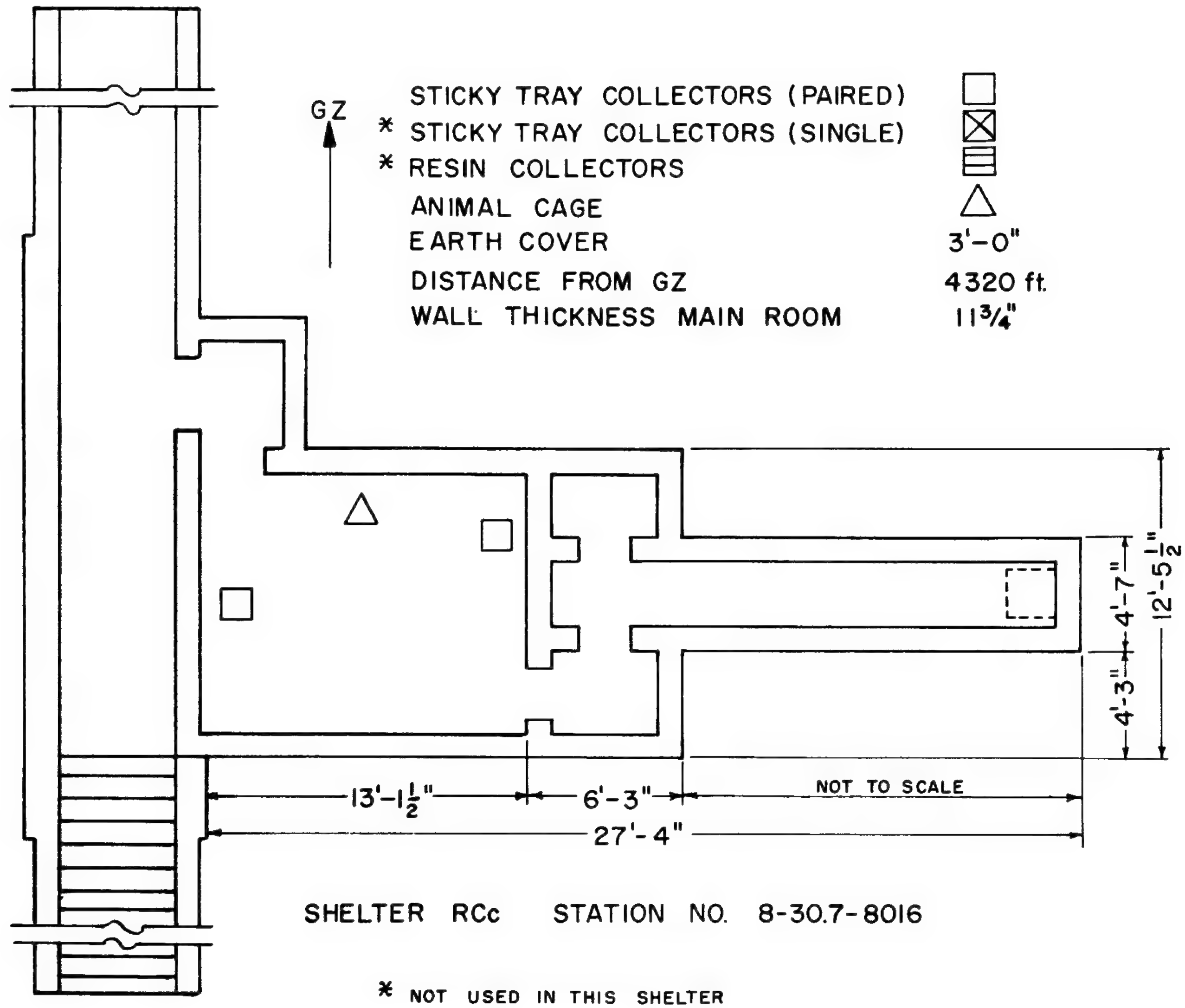


Fig. 2.13—Diagram of structure RCc (Smoky).

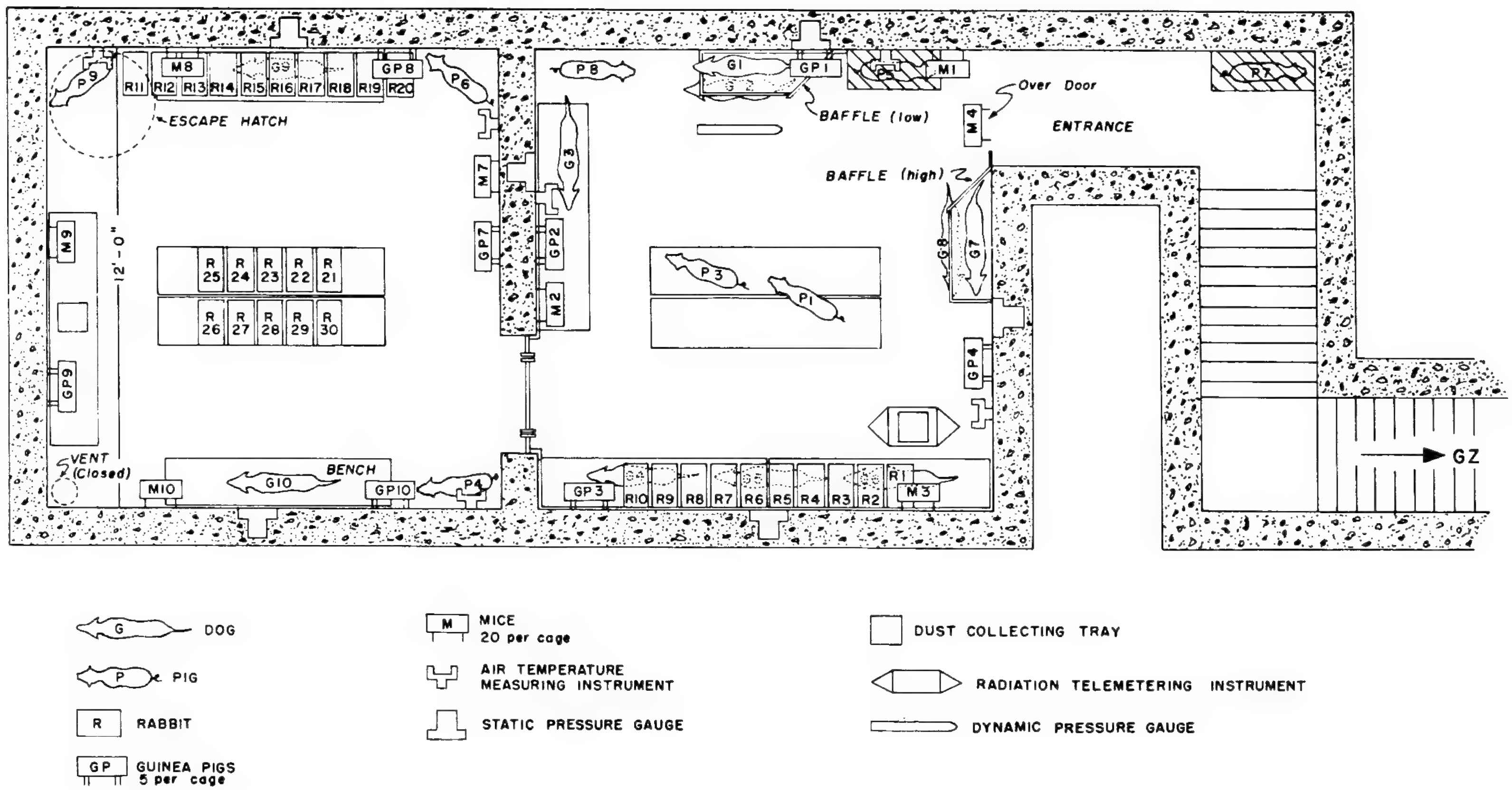


Fig. 2.14—Diagram of blast biology shelter (Galileo).

Table 2.3—TIME PRISCILLA DUST COLLECTORS EXPOSED AND RECOVERED

| Structure No. | Distance from GZ, ft | Dust collector type* | Day shelter button-up | Day dust collectors exposed | | | Day dust collectors recovered |
|---|---|---|---|---|---|---|---|
| | | | | | Control | Exper. | |
| | | A | | D-4 | | | D+4 |
| F3.1-9014.01 | 860 | B | D-2 | | D-4 | D-2 | D+4 |
| | | A | | D-4 | | | D+4 |
| F3.1-9014.02 | 1040 | B | D-2 | | D-4 | D-2 | D+4 |
| | | A | | D-4 | | | D+4 |
| F3.1-9014.03 | 1360 | B | D-2 | | D-4 | D-2 | D+4 |
| | | A | | D-4 | | | D+4 |
| F3.1-9015 | 1360 | B | D-2 | | D-4 | D-2 | D+4 |
| | | A | | D-4 | | | D+8 |
| F3.2-9017.01 | 1040 | B | D-3 | | D-4 | D-3 | D+8 |
| | | A | | D-4 | | | D+8 |
| F3,2-9017.02 | 1150 | B | D-3 | | D-4 | D-3 | D+8 |
| | | A | | D-4 | | | D+8 |
| F3.2-9017.03 | 1360 | B | D-3 | | D-4 | D-3 | D+8 |
| | | A | | D-4 | | | D+3 |
| F3.3C-9019.02 | 1360 | B | D-2 | | D-4 | D-2 | D+3 |

*Dust collector type A = microscope slides.
Dust collector type B = sticky-paper trays, paired.

Table 2.4—TIME SMOKY AND GALILEO DUST COLLECTORS EXPOSED AND RECOVERED

| Structure No. | Distance from GZ, ft | Dust collector type* | Day final button-up | Control collectors Day exposed | Control collectors Day recovered | Exper. collectors Day exposed | Exper. collectors Day recovered |
|---|---|---|---|---|---|---|---|
| RAa-8008 | 840 | B | D-1 | D-14 | D-13 | D-3 | D+2 |
| | | C | | | | D-3 | D+2 |
| | | D | | | | D-3 | D+2 |
| CAa-8009 | 900 | B | D-1 | D-14 | D-13 | D-3 | D+2 |
| RAb-8010 | 900 | B | D-1 | D-14 | D-13 | D-3 | D+2 |
| RAc-8011 | 1005 | B | D-1 | D-14 | D-13 | D-1 | D+2 |
| | | B | | D-3 | D-1 | | |
| CAb-8012 | 1005 | B | D-1 | D-14 | D-13 | D-1 | |
| | | C | | | | D-1 | |
| | | D | | | | D-1 | |
| | | E | | | | D-1 | D+12 |
| RAd-8013 | 1176 | B | D-1 | D-14 | D-13 | D-3 | D+2 |
| | | C | | | | D-3 | D+2 |
| | | D | | | | D-3 | D+2 |
| RCa-8014 | 1770 | B | D-1 | D-14 | D-13 | D-1 | D+2 |
| | | B | | D-3 | D-1 | | |

Table 2.4—TIME SMOKY AND GALILEO DUST COLLECTORS EXPOSED AND RECOVERED (Continued)

| Structure No. | Distance from GZ, ft | Dust collector type* | Day final button-up | Control collectors | | Exper. collectors | |
|---|---|---|---|---|---|---|---|
| | | | | Day exposed | Day recovered | Day exposed | Day recovered |
| RCb-8015 | 2340 | B | D-1 | D-14 | D-13 | D-1 | D+2 |
| | | C | | | | D-1 | D+2 |
| | | D | | | | D-1 | D+2 |
| RCc-8016 | 4320 | B | D-1 | D-14 | D-13 | D-1 | D+2 |
| | | B | | D-3 | D-1 | | |
| 1-33.1-8001 | 1050 | B | D-1 | | | D-1 | H+4 hr |

*Dust collectors type B = sticky paper trays, paired.
Dust collectors type C = sticky paper trays, single.
Dust collectors type D = sticky resin trays.
Dust collectors type E = air sampler.

### 2.5.2 Smoky

Times of exposure and recovery of type B, C, D, and E dust collectors are detailed in Table 2.4. Twelve of the control trays (type B) were installed and uncovered the afternoon of D-14, at which time dust on the floor was stirred up by swatting the floor with a piece of cardboard. These 12 trays, designated as "dirty" controls in Table 2.2, were recovered on the morning of D-13. Three other type B trays were used as "clean" controls (see Table 2.4) and were uncovered on D-3 and recovered on D-1. These controls were in structures in which activities of other projects had significantly contaminated experimental trays installed on D-3.

Experimental type B, C, and D dust collectors were exposed on D-3 or D-1, as shown in Table 2.4. Recovery of all dust trays was accomplished on D+2.

The air sampler, fuel, and a gasoline-driven generator were installed on D-6 in the main room of structure CAb, as shown in Fig. 2.9. Exhaust gases were piped to the exterior through flexible tubing passing from the generator exhaust through the inner wall of the lock to the outer ventilation duct which was guarded by a one-way flapper valve allowing exhaust gases to flow outward. Short preshot tests indicated that sufficient fresh air entered through the inlet portion of the ventilation system. However, a prolonged test on D-2 indicated that this arrangement was inadequate owing to a faulty piston-ring seal in the generator which allowed exhaust gases to pass into the crankcase and reach the air in the shelter through the oil-vent opening. Although the generator was unlikely to function from H-6 hr, at which time it was turned on, even until shot time, there was no opportunity to move the generator from the main room of the structure or to provide power ventilation, either of which would have, no doubt, proved satisfactory.

### 2.5.3 Galileo

A single type B tray was uncovered in each compartment of the Galileo shelter at the time of button-up near midnight on D-1. Recovery was accomplished 4 hr after the shot, at which time each collector was covered with a dummy tray. Later each transparent paper was stripped from the trays, cut in half, and paired, sticky face to sticky face.

Chapter 3

# RESULTS

## 3.1 PAIRED STICKY-PAPER COLLECTORS (TYPE B)

After recovery the transparent papers were stripped from the trays and were available for gross inspection and documentary photography. The latter was accomplished using transmitted and reflected light simultaneously, a technique which yielded quite pictorial reproductions of the original preparations. These, along with preliminary data from gross inspection of the trapped material, are presented below.

### 3.1.1 Priscilla

(a) The 3.1 Concrete-arch Structures. Figs. 3.1 to 3.4, inclusive, show the results for the arch structures located 860, 1040, and 1360 ft from GZ on the Priscilla shot. There was little difference between the control and experimental sides of the dust collectors. However, the control side in Fig. 3.4 was slightly, but definitely, denser than the experimental side. The general similarity between the control and experimental data indicate that most of the grossly visible material trapped by the dust collectors was post-shot and not preshot debris. This follows because the experimental side of the tray was not uncovered until button-up, an activity which stirred up very little dirt.

This conclusion is further supported by the evident effect of range on the total amount and gross particle size of the material captured, e.g., compare Figs. 3.1, 3.2, 3.3, and 3.4 for the 860-, 1040-, and 1360-ft ranges, respectively. The largest particulates are seen in Fig. 3.1 at the closest range, some being as sizable as 5/16 in. in diameter, with a few slivers 3/8 in. long by 1/8 in. wide. It is of interest to note that some of the particles shown in Fig. 3.1 were definitely hard concrete, and others were of softer material,

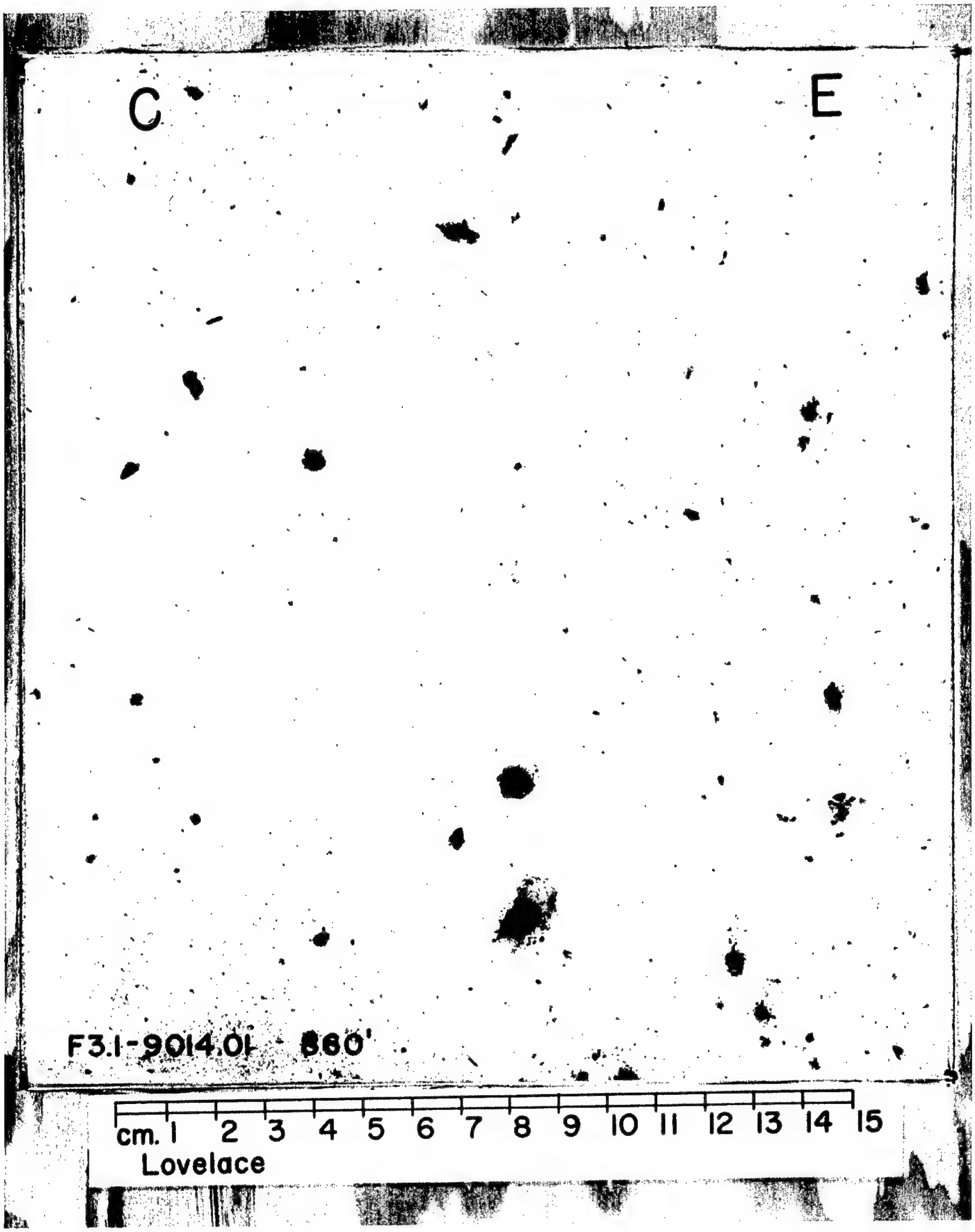


Fig. 3.1—Type B dust collector from concrete arch shelter F3.1-9014.01 (Priscilla).

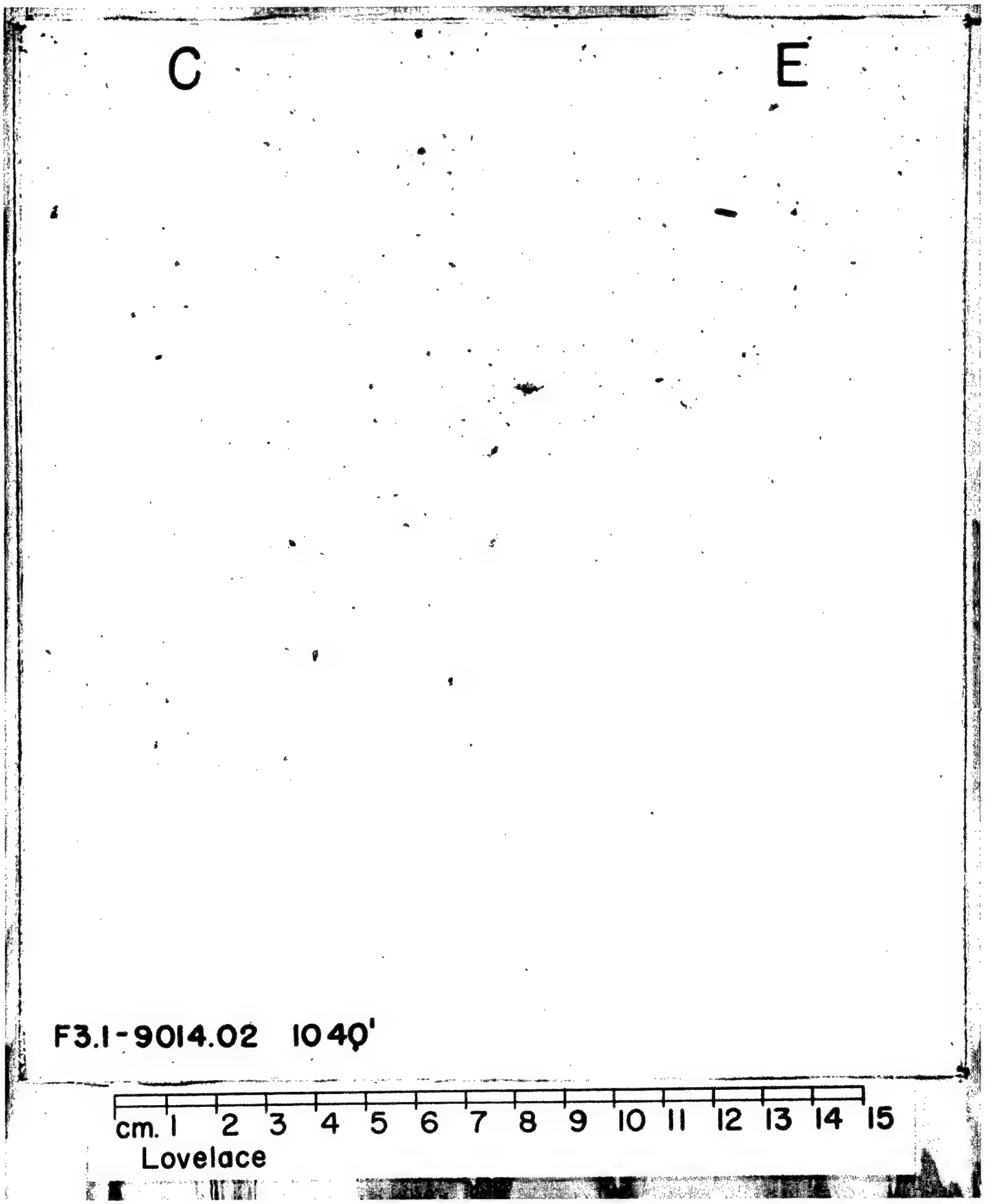


Fig. 3.2—Type B dust collector from concrete arch shelter F3.1-9014.02 (Priscilla).

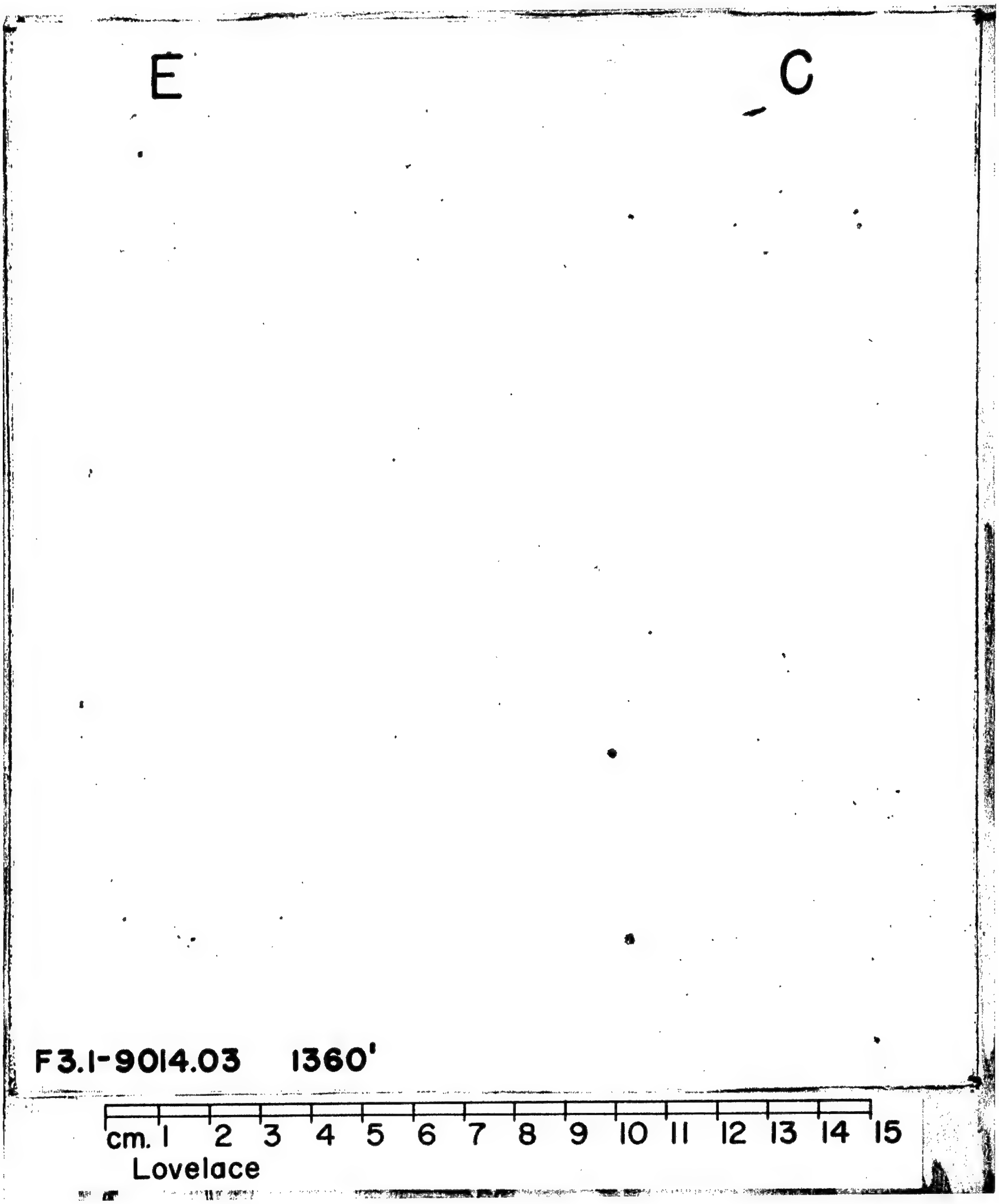


Fig. 3.3—Type B dust collector from concrete arch shelter F3.1-9014.03 (Priscilla).

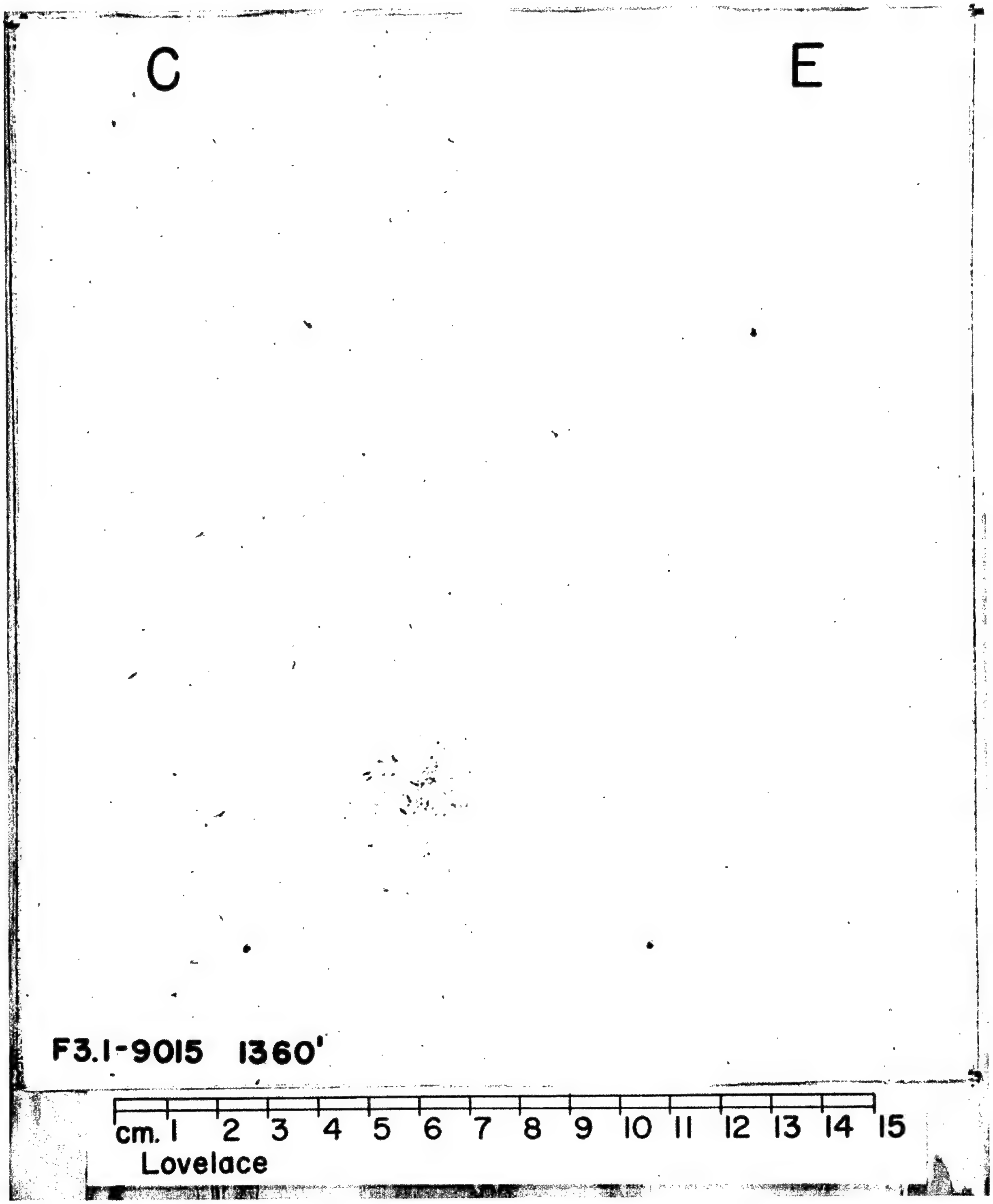


Fig. 3.4—Type B dust collector from concrete arch shelter F3.1-9015 (Priscilla).

such as mortar mixed with cement. This finding prompted a careful inspection of the F3. 1-9014. 01 shelter, and the source of the soft particulates was easily established. Just above one of the trays several defects in the original concrete had been patched with cement mortar. This spalled in considerable amount along with some of the harder concrete of the main structure. Such a finding cautions against patching the inner surfaces of shelters designed for blast protection because certainly there is enough coupling between the air shock and the soil and the soil and the structure to cause spalling of any material which does not have a firm bond with the structure wall.

Note that Fig. 3. 2 (1040-ft range) is intermediate in the amount of material captured between Fig. 3. 1 and Figs. 3. 3 and 3. 4, the last two preparations, applicable to the 1360-ft range, being only slightly contaminated as far as gross inspection was concerned.

Even the grossly "clean" preparations when viewed with a microscope are somewhat "dirty", but as yet no data on microscopic sizing of fine material are available.

(b) The 3. 2 Circular Concrete Structures. Results applicable to the three circular 3. 2 structures are in sharp contrast with those just noted for the arch 3. 1 shelters. The difference will be readily apparent from a study of Figs. 3. 5, 3. 6, and 3. 7 showing the transparent preparations from the trays recovered from those structures at 1040, 1150, and 1360 ft, respectively. First, the apparent effect of range was less marked for the 3. 2 than for the 3. 1 structures, although it was true that there were more of the larger and harder concrete particles at the near compared with the far range. Second, many of the particles captured proved to be pieces of wood and much dirt. This occurred because the end bulkheads of the circular structures were of wooden construction. The wood "spalled, " and dirt was forced into the shelters through the small cracks separating the timbers, thus accounting for the third difference between the arch and circular structures; namely, the heavier contamination of the trays recovered from the circular shelters.

(c) The 3. 3C Steel-arch Structure. Photographs of the two paired dust collectors recovered from the steel quonset structure are shown in Figs. 3. 8 and 3. 9. The structure preshot was quite clean, and the relative pre- and postshot contamination of the dust collectors apparent in the figures suggests that the steel arch on concrete is a useful means of avoiding dirt in blast-protective structures. However, the concrete-arch structures at the same range (1320 ft) also proved "clean," and the data are not sufficient to indicate whether or not the concrete deck in the 3. 3C shelter would have spalled if exposure had been much closer to GZ.

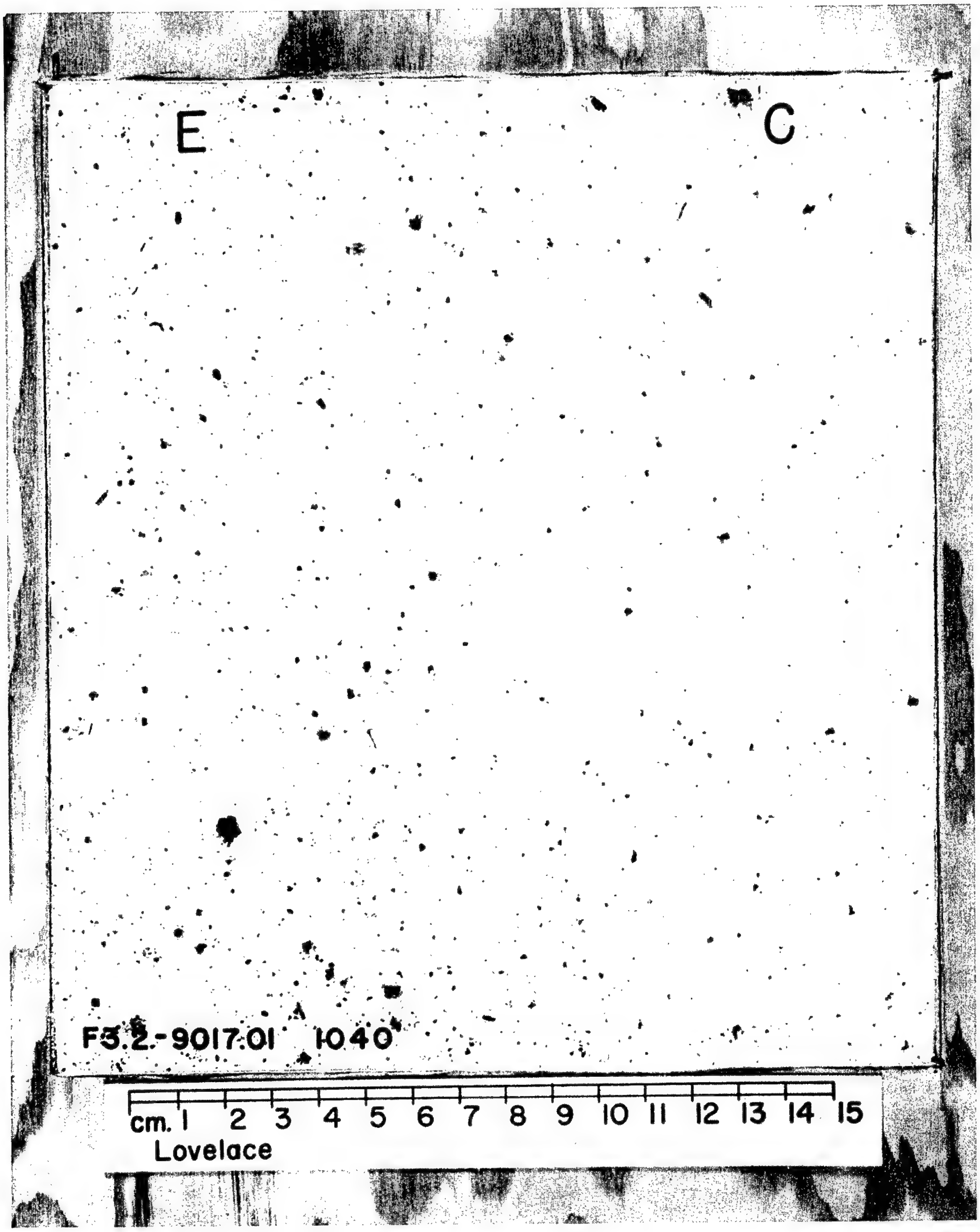


Fig. 3.5—Type B dust collector from concrete circular shelter F3.2-9017.01 (Priscilla).

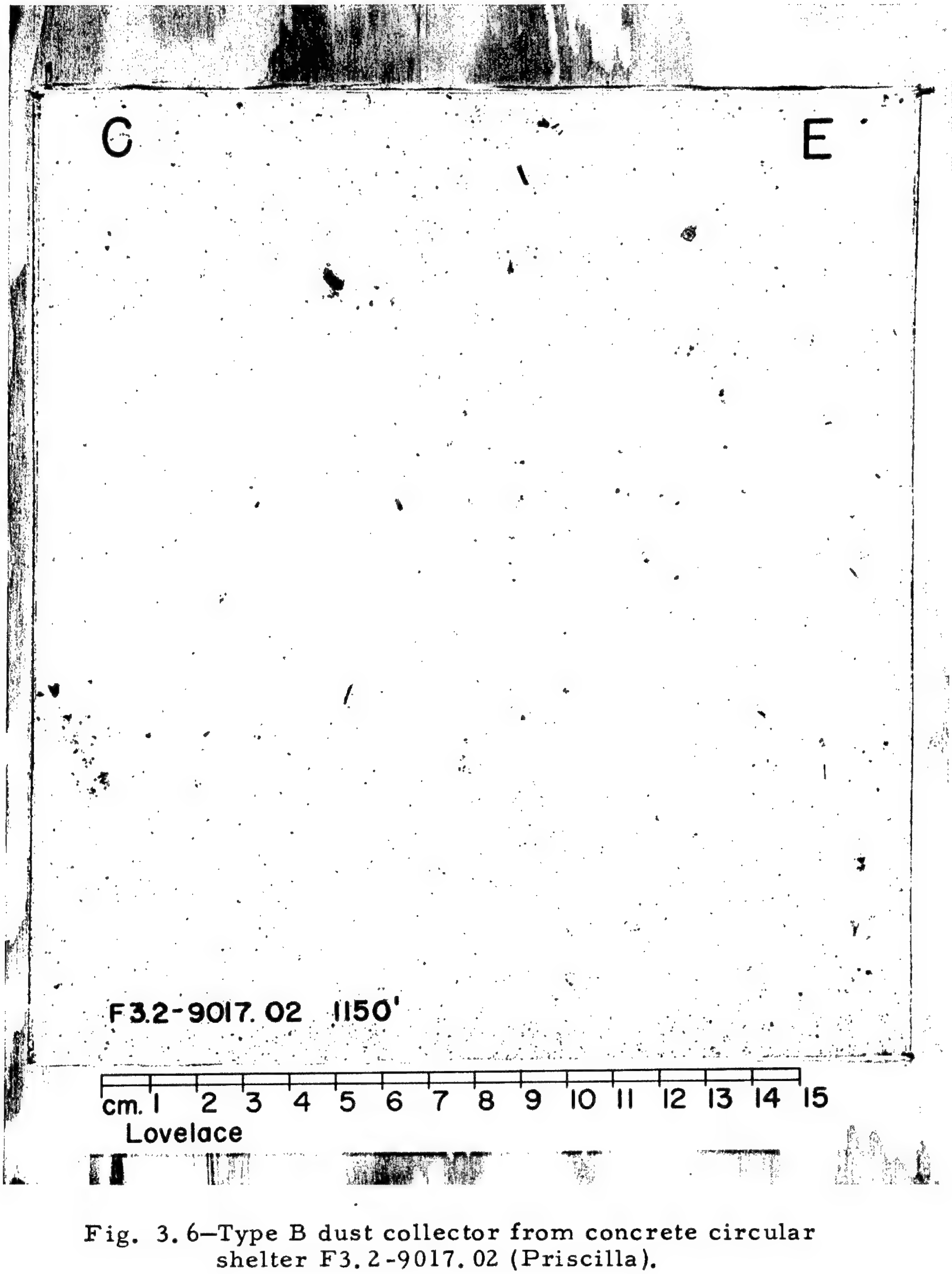


Fig. 3.6—Type B dust collector from concrete circular shelter F3.2-9017.02 (Priscilla).

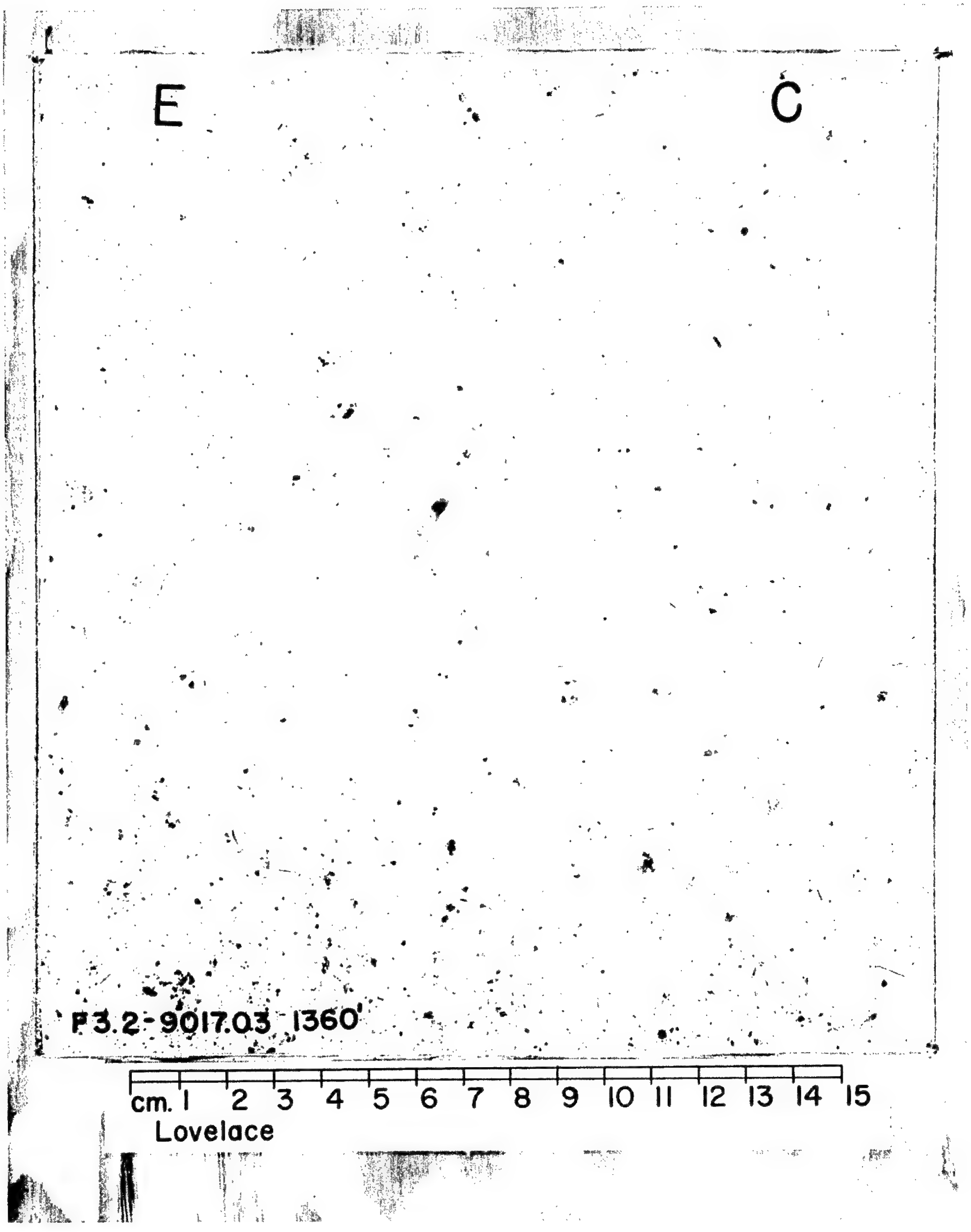


Fig. 3.7—Type B dust collector from concrete circular shelter F3.2-9017.03 (Priscilla).

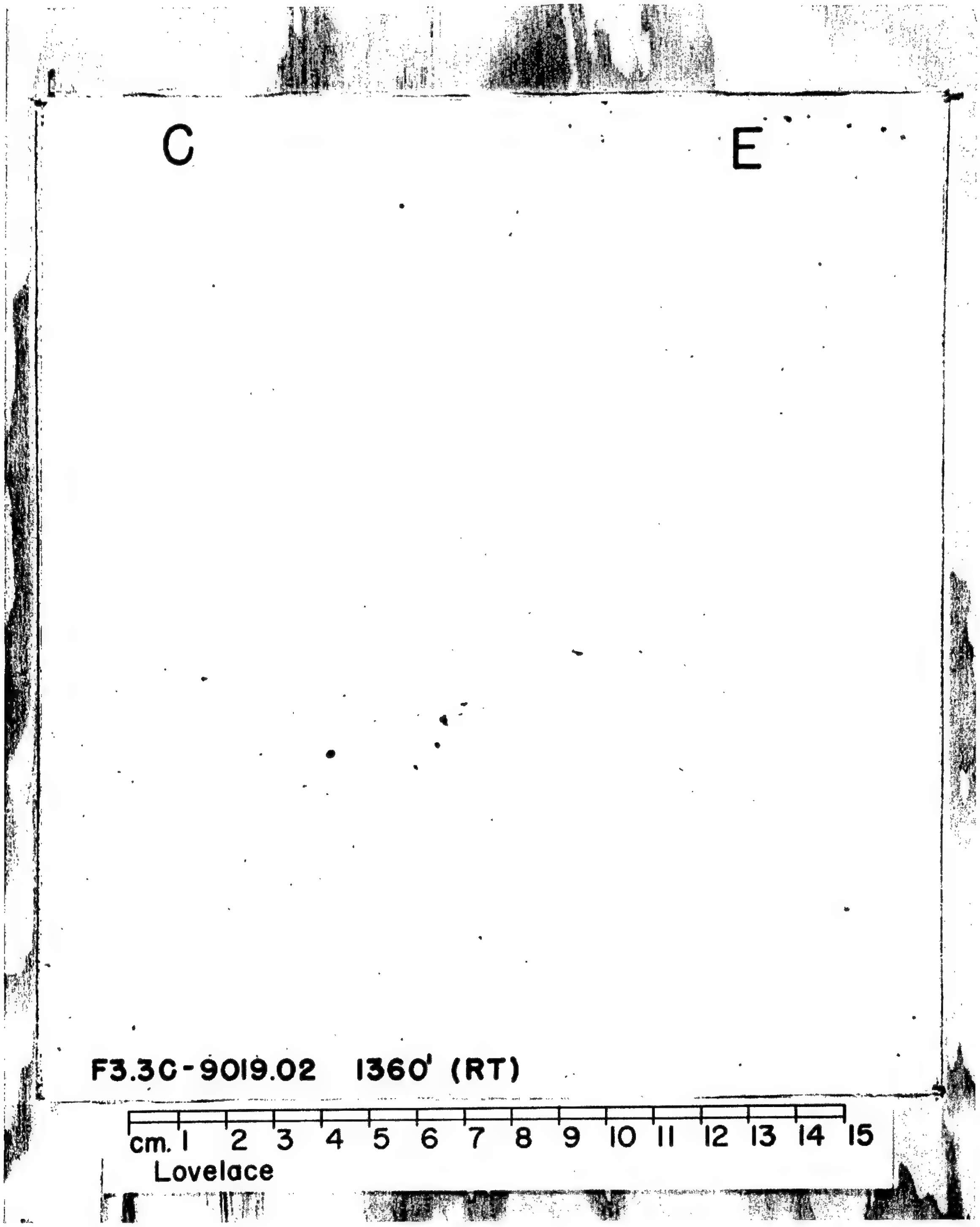


Fig. 3.8—Type B dust collector (right side) from steel arch shelter F3.3C-9019.02 (Priscilla).

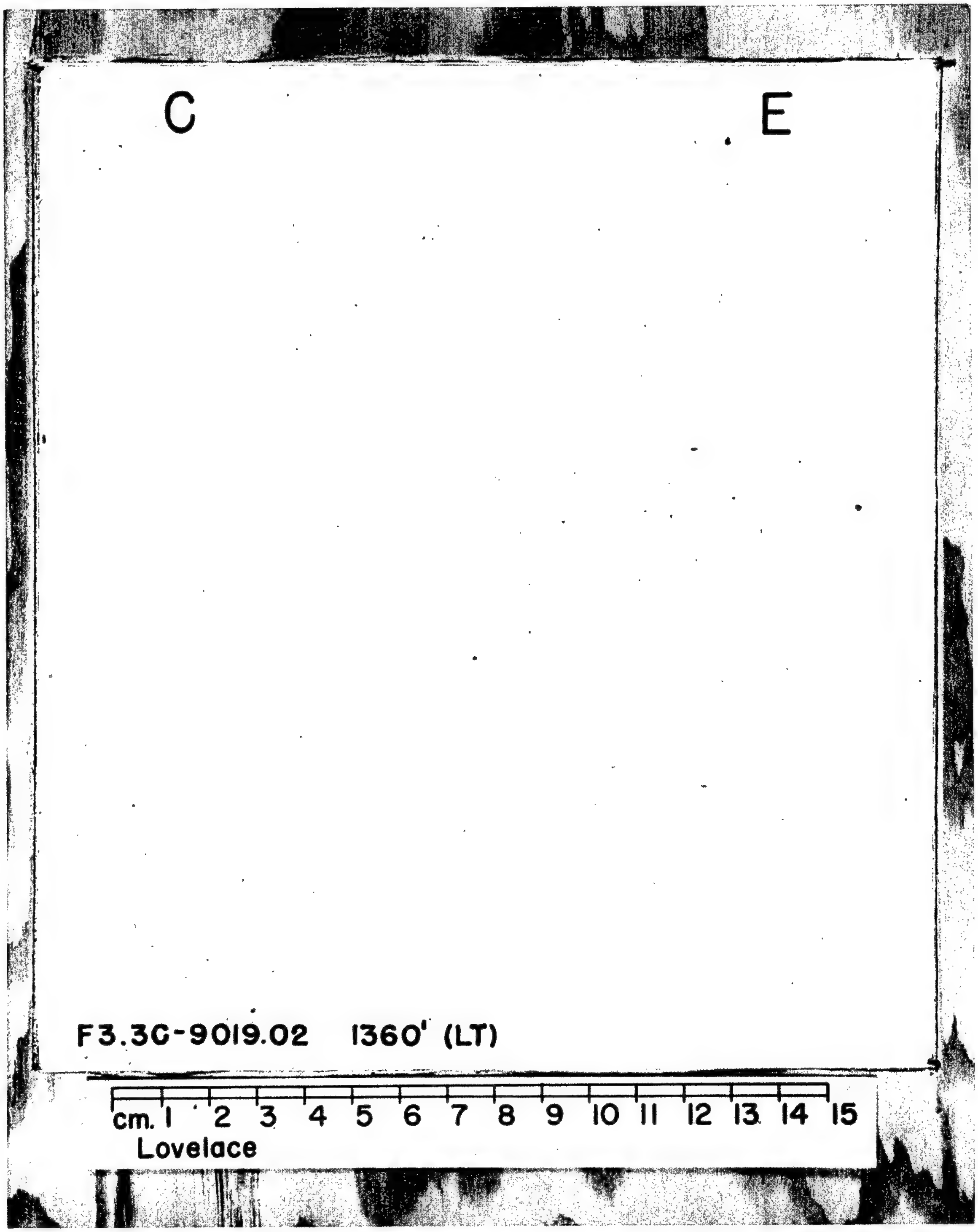


Fig. 3.9—Type B dust collector (left side) from steel arch shelter F3.3C-9019.02 (Priscilla).

3.1.2 Smoky

(a) RA Shelters. Four heavier rectangular structures, RAa, RAb, RAc, and RAd, located 840, 900, 1005, and 1176 ft from GZ, respectively, can be treated as a group. Figs. 3.10 to 3.13 show the particulate material contaminating the type B experimental, paired sticky-paper collectors removed from the structures. For comparison, Fig. 3.14 shows a paired sticky-paper control prepared under clean conditions in the laboratory and photographed in the same way. A variation with range, as was the case with the Priscilla shelters, was noted and is apparent from the figures, particularly with regard to the size and number of the gross particles to be seen in the 840-ft structure (Fig. 3.10) compared with those at 900, 1005, and 1176 ft. The material on the 8008 preparation was composed mostly of dirt, but a few small hard pieces of concrete were easily identified.

Not too evident from the figures, but very much so from the original preparations was the presence of a considerable amount of very fine dust on the trays from the 8010 (RAb), 8011 (RAc), and 8013 (RAd) shelters. This was particularly surprising in the case of the 8013 structure, which was vacuum cleaned on D-1 (see Table 2.2). The presence of very fine dust, which was in contrast to the "closed" Priscilla structures, was verified postshot by inspection of the shelters and samples from the floor. This finding tempts one to draw the conclusion that there was a "leak" in the forward rectangular structures. Since the main and escape hatch doors were all found closed on recovery by Program 33 personnel, who were the first to enter all the structures, and since no structural failure or open conduits were noted, about the only portion of the shelter left to "suspect" is the ventilation system.

It was postulated that the fine dirt found in the shelters was blown in through the ventilation ducts, one of which was present in each structure. If this is true, the dirt either was present in the duct preshot or was present preshot inadvertently as a contaminant in the sand filter guarding the ventilation intake assembly, or it arose from outside, being blown by the blast winds down the ventilation shaft and through the sand filter.

The experimental findings and the postulated explanation were made known to Program 30 personnel, who are cooperating in establishing a satisfactory explanation. To date, it is known that the covers over several of the vertical air intake shafts failed and considerable dirt was blown into the outer passages of the ventilation airway. Examination of the sand in the filter and disassembly of the air impeller located inside the structure is to be accomplished by the responsible architectural and engineering personnel, but no definite information is available at this time.

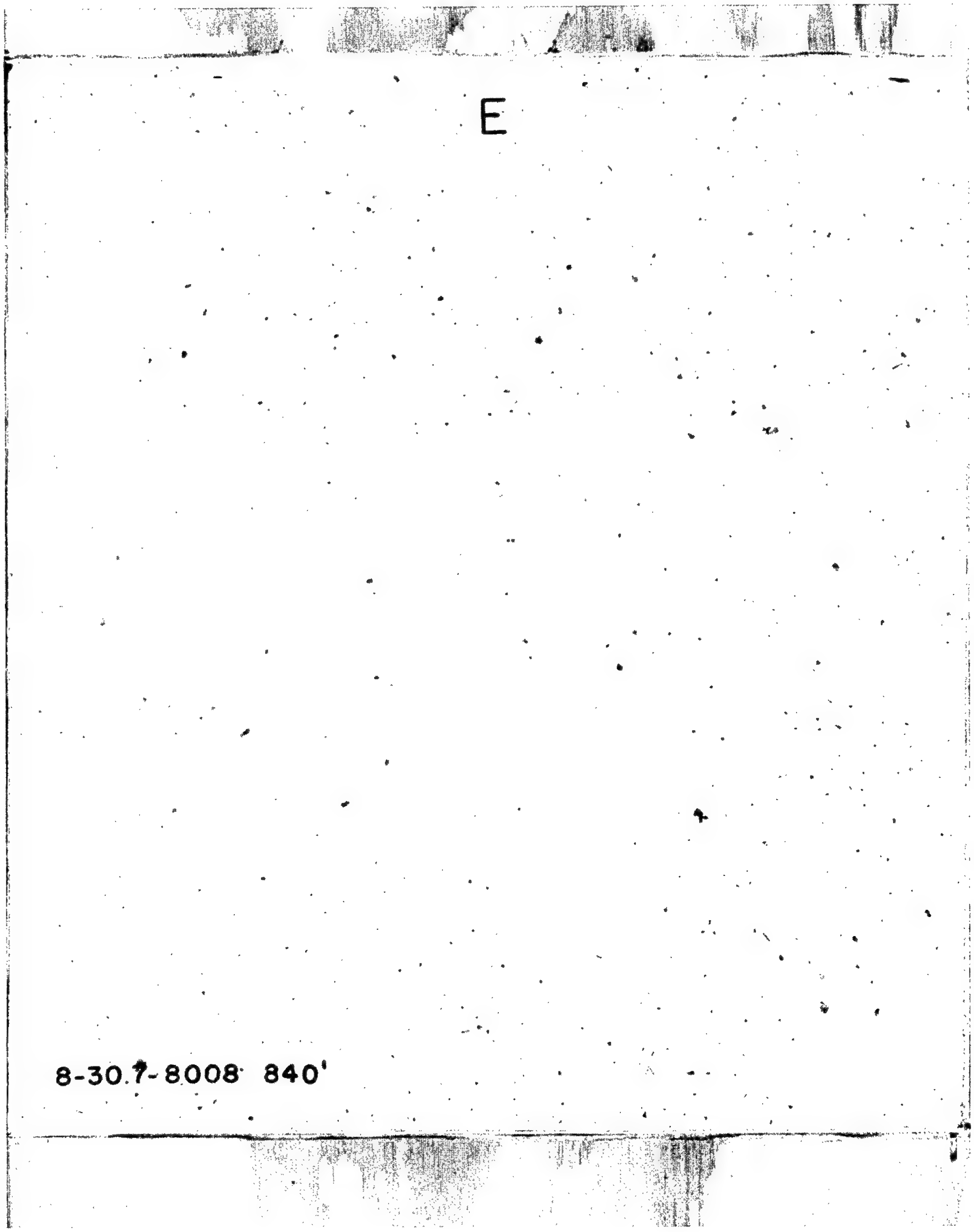


Fig. 3.10—Type B experimental dust collector from rectangular structure RAa (8-30.7-8008)(Smoky).

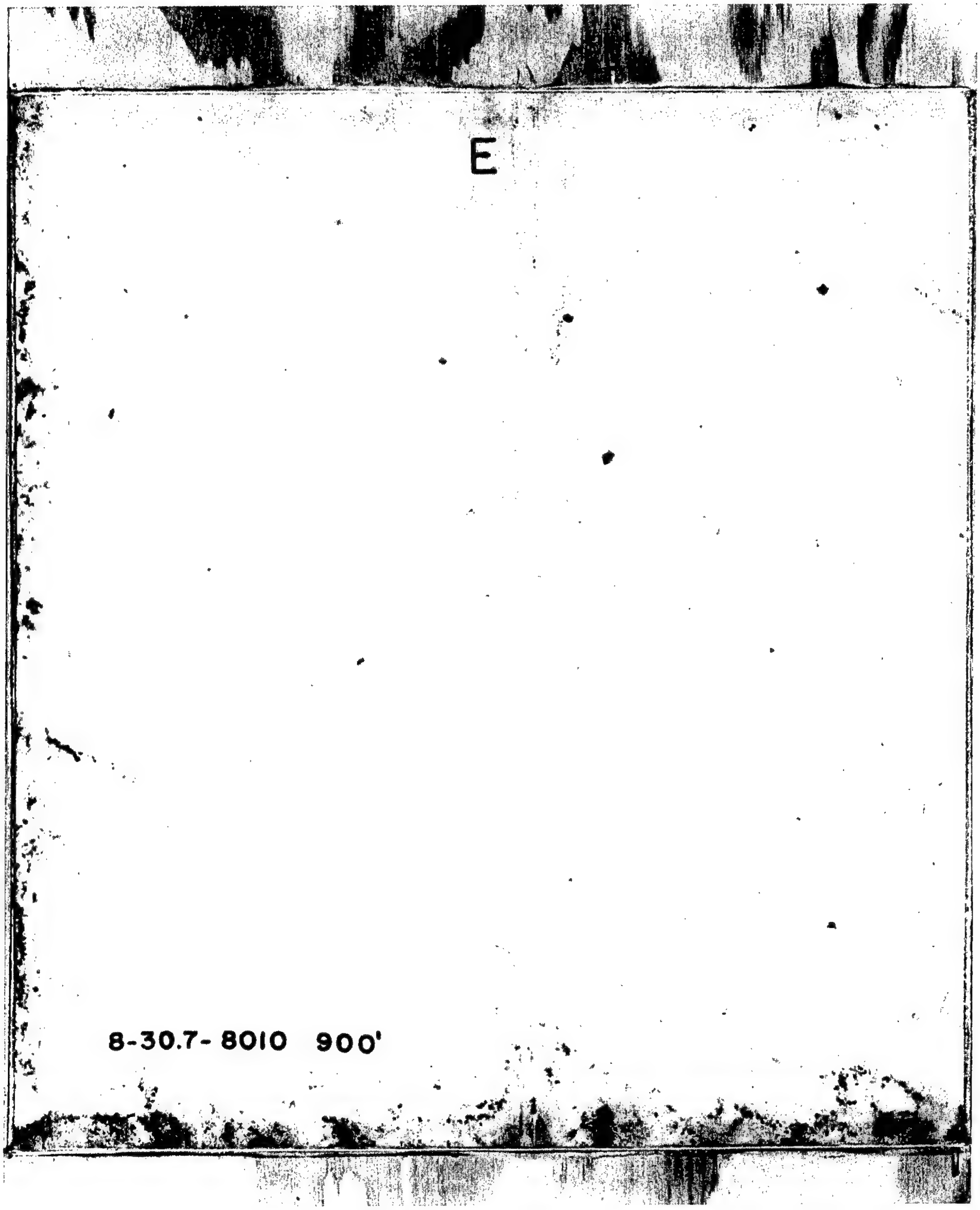


Fig. 3.11—Type B experimental dust collector from rectangular structure RAb (8-30.7-8010) (Smoky).

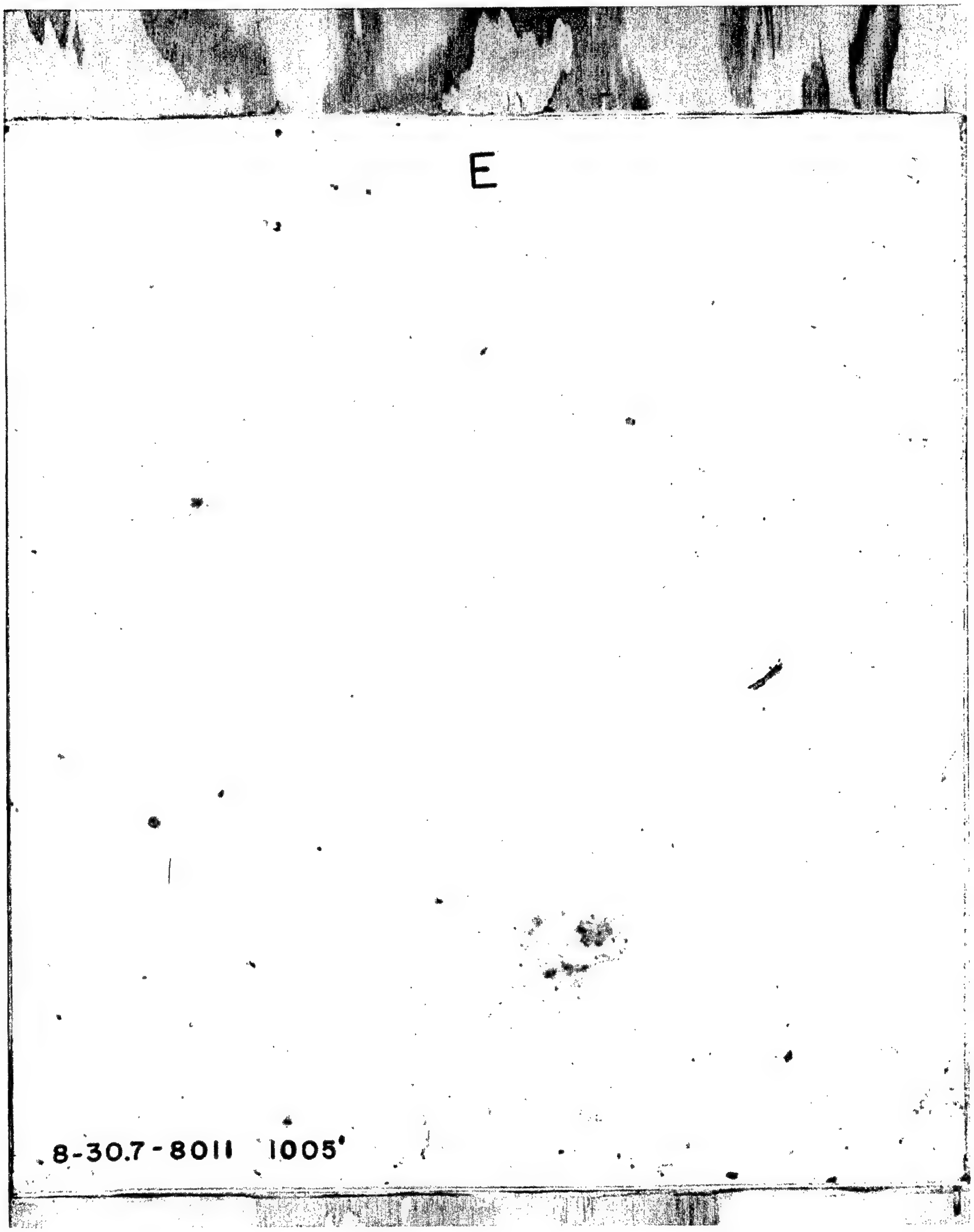


Fig. 3.12—Type B experimental dust collector from rectangular structure RAc (8-30.7-8011) (Smoky).

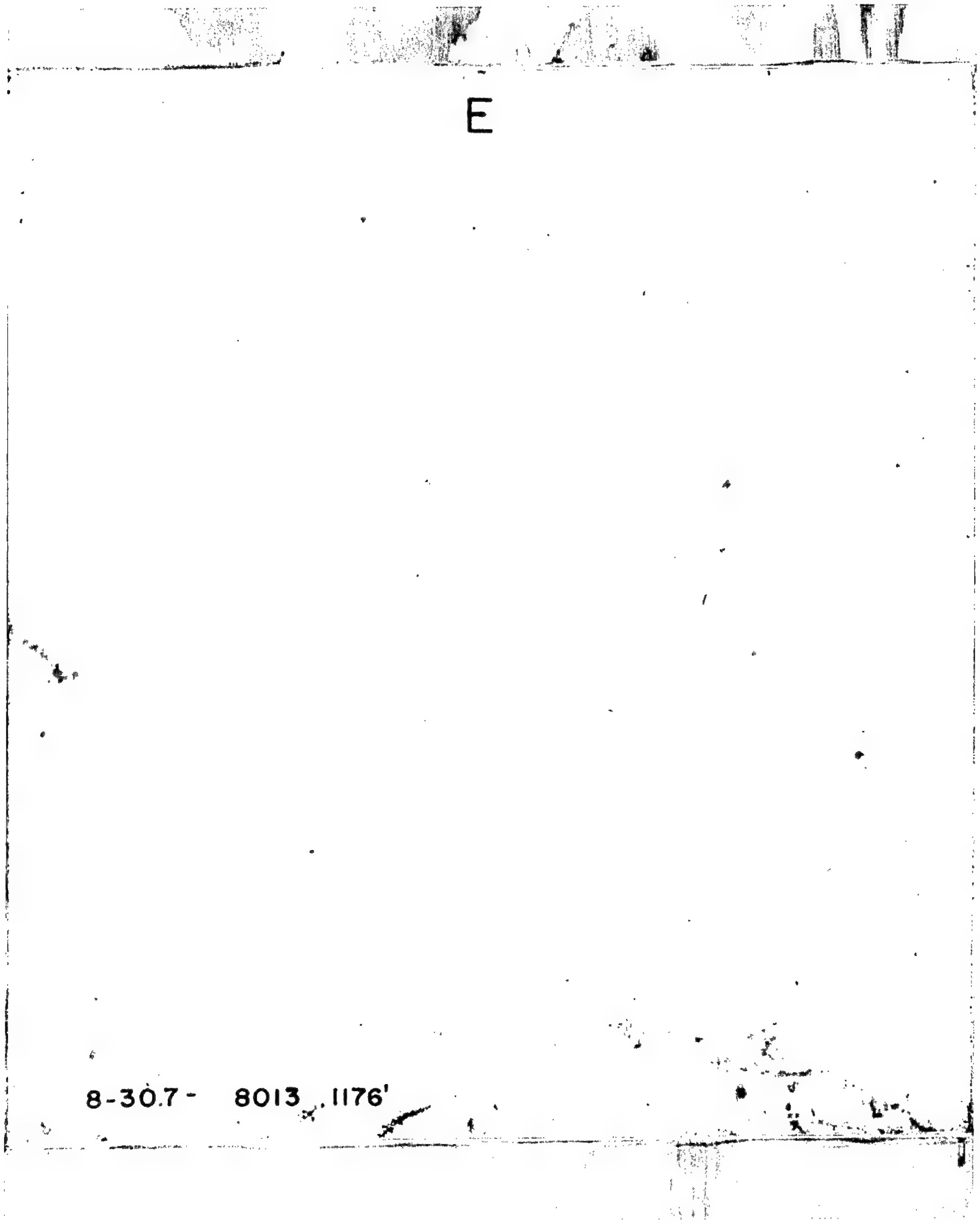


Fig. 3.13—Type B experimental dust collector from rectangular structure RAd (8-30.7-8013) (Smoky).

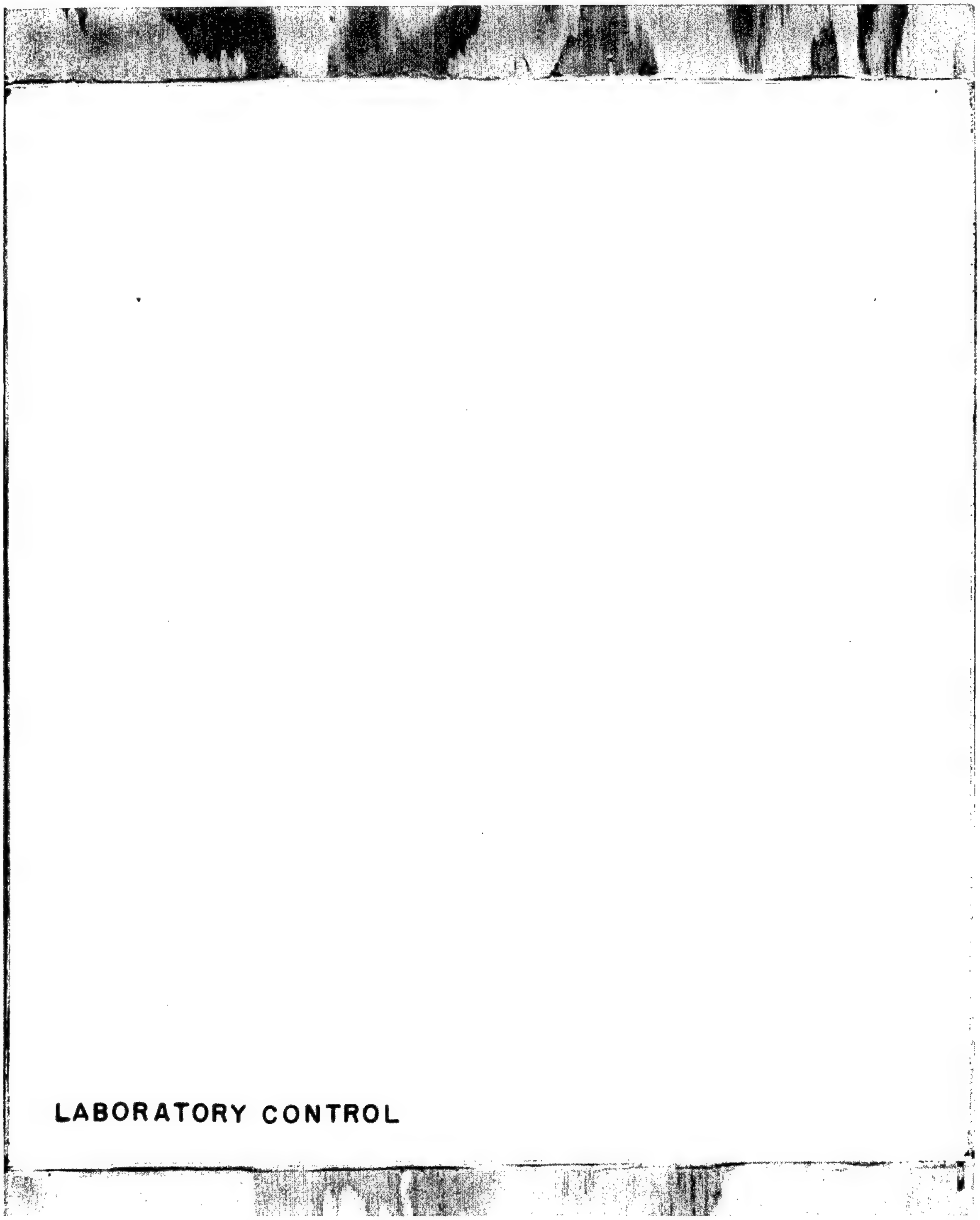


Fig. 3.14—Paired sticky-paper laboratory control.

(b) RC Structures. Figs. 3.15, 3.16, and 3.17 show the data documented from the type B experimental dust collectors for the lighter rectangular structures RCa, b, and c, respectively, located 1770, 2430 and 4320 ft from GZ. Two of these, RCb and RCc, were vacuum cleaned on D-1. It is obvious from the figures that gross contamination with dust was minimal.

(c) Circular CA Structures. Figs. 3.18 and 3.19 show the photographic data obtained from the experimental dust collectors placed in circular structures CAa and CAb, located 900 and 1005 ft, respectively, from GZ. Again, a variation with range was apparent, much larger and many more particulates being visible on the preparation from the closer structure. However, the farther CAb shelter (8012) was vacuum cleaned on D-1, and 8009, which was fairly dirty preshot, was not. Even so, more hard concrete particulates were evident on inspection of the original preparations from the CAa (8009) than on those from the CAb (8012) shelter.

(d) Control Collectors. Photographs of the twelve control collectors are available, but, although they will be useful in future analyses, including them all here would serve no useful purpose. Figs. 3.20 and 3.21, the "dirty" and "clean" controls placed in the RCc (8016) structure, are shown as a matter of general interest.

### 3.1.3 Galileo

The type B dust collector recovered from both the fast- and slow-fill sides of the 33.1 shelter used on the Galileo shot were heavily contaminated with dirt. Fig. 3.22 shows results. The heavy contamination of the dust collectors from the Galileo structure placed at a range of 1050 ft from GZ and tested with the entry way and escape hatch open was in sharp contrast to the results seen in shelters tested with all vents and hatches closed. The Galileo results are worth considering simply to give the reader a gross idea of the amount of debris and dirt which is carried into open structures and which would inevitably settle on all animate or inanimate objects housed in the shelter. However, although the thick dust was most annoying to recovery personnel, the amount was of no immediate consequence, which also proved to be the case with experimental animals recovered from the Galileo structure. (See ITR-1507, reporting observations on experimental animals by Project 33.6.)

## 3.2 SINGLE STICKY-PAPER (TYPE C) AND STICKY-RESIN (TYPE D) COLLECTORS

The four single sticky-paper and sticky-resin collectors placed in the structures that were treated with fluorescent dye (see Tables 2.2 and 2.4) were recovered without incident. Later at the

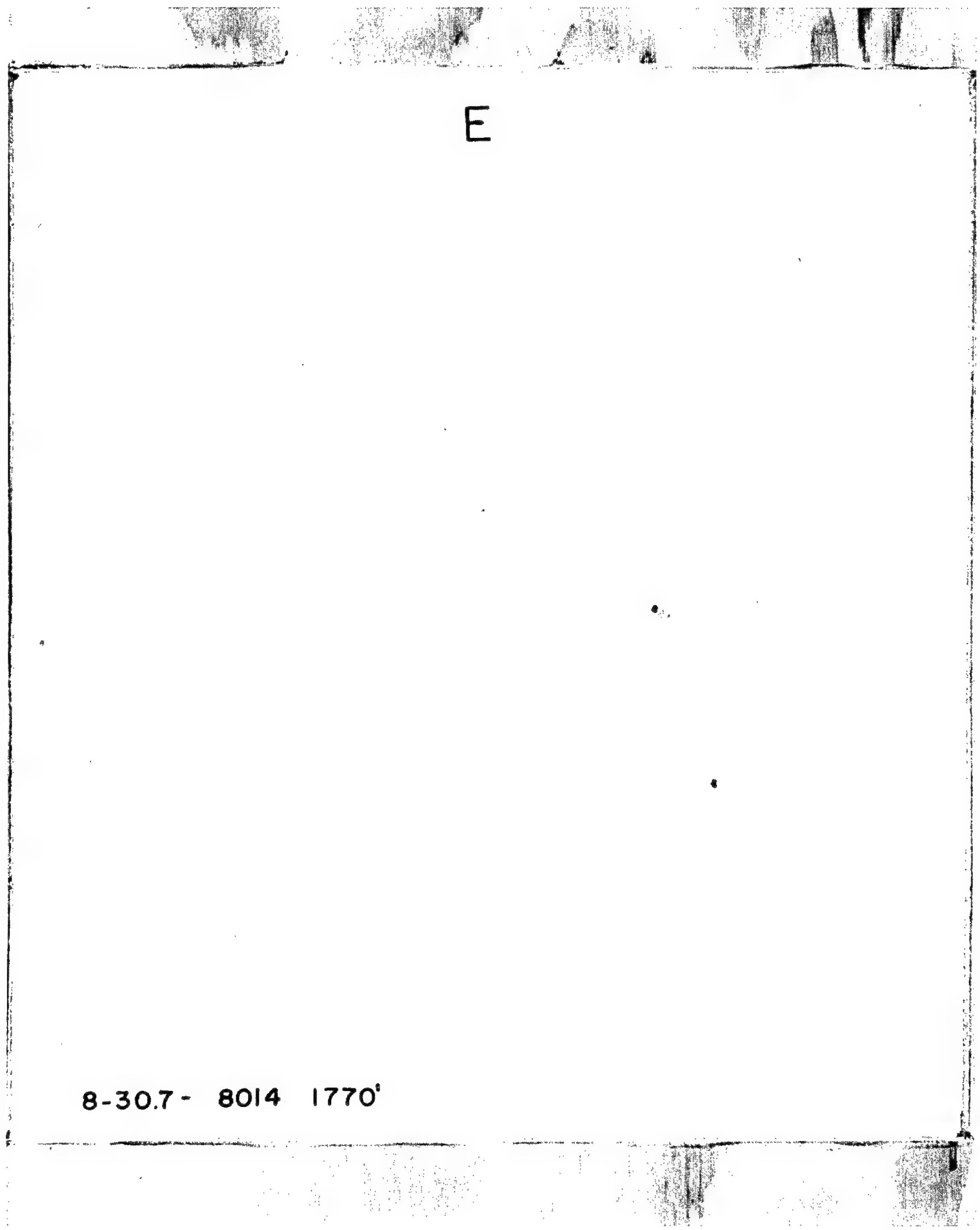


Fig. 3.15—Type B experimental dust collector from rectangular structure RCa (8-30.7-8014) (Smoky).

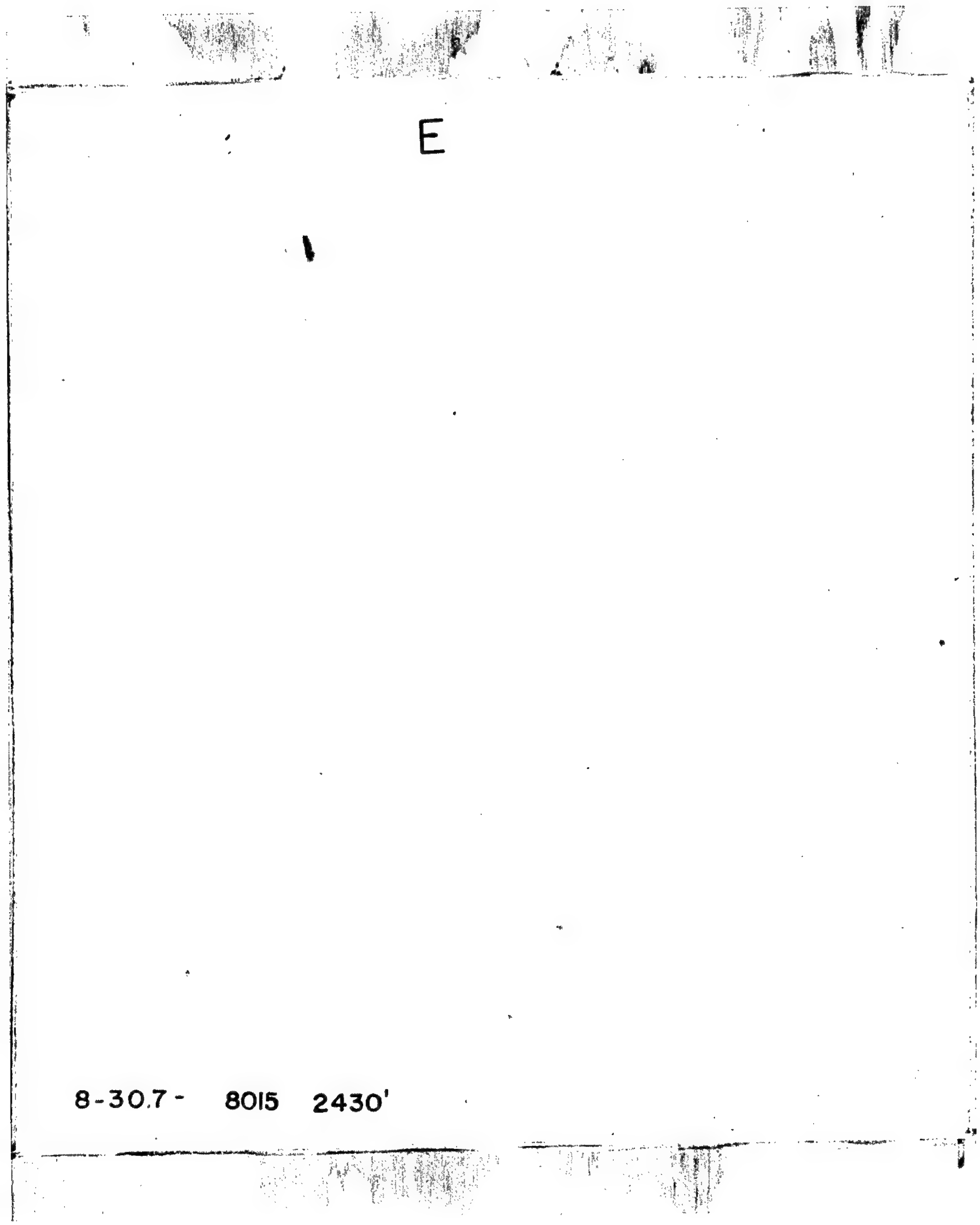


Fig. 3.16—Type B experimental dust collector from rectangular structure RCb (8-30.7-8015) (Smoky).

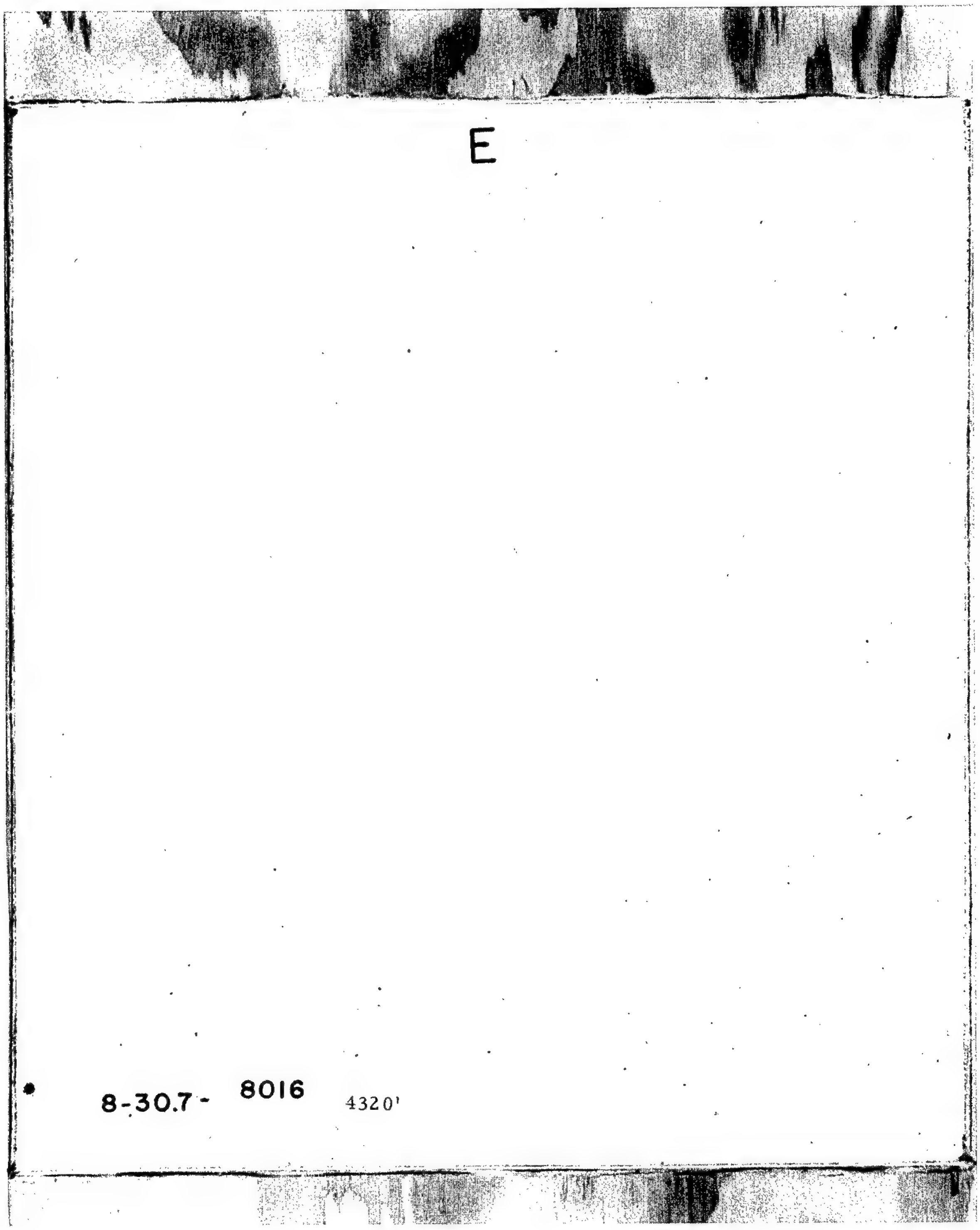


Fig. 3.17—Type B experimental dust collector from rectangular structure RCc (8-30.7-8016) (Smoky).

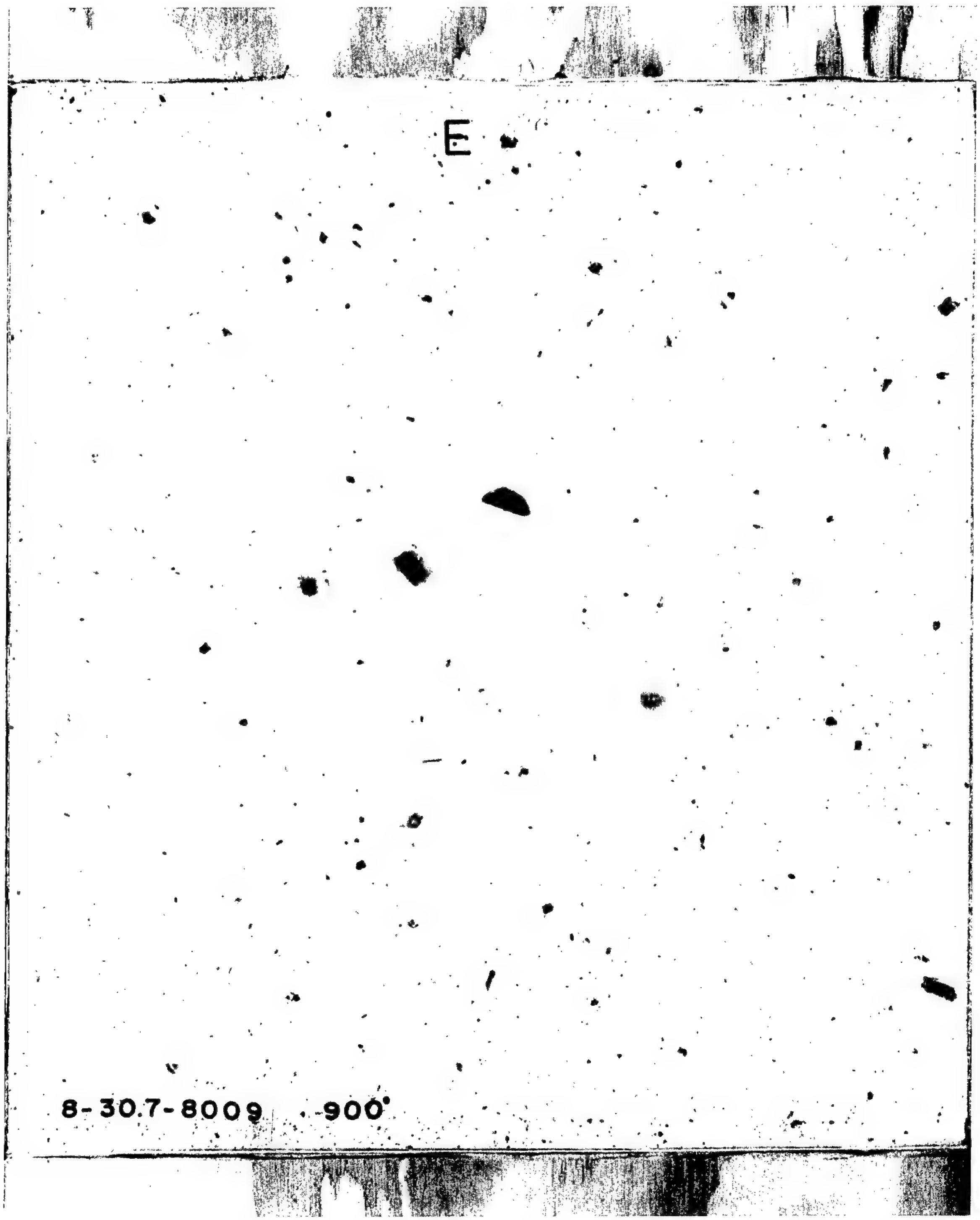


Fig. 3.18—Type B experimental dust collector from circular structure CAa (8-30.7-8009) (Smoky).

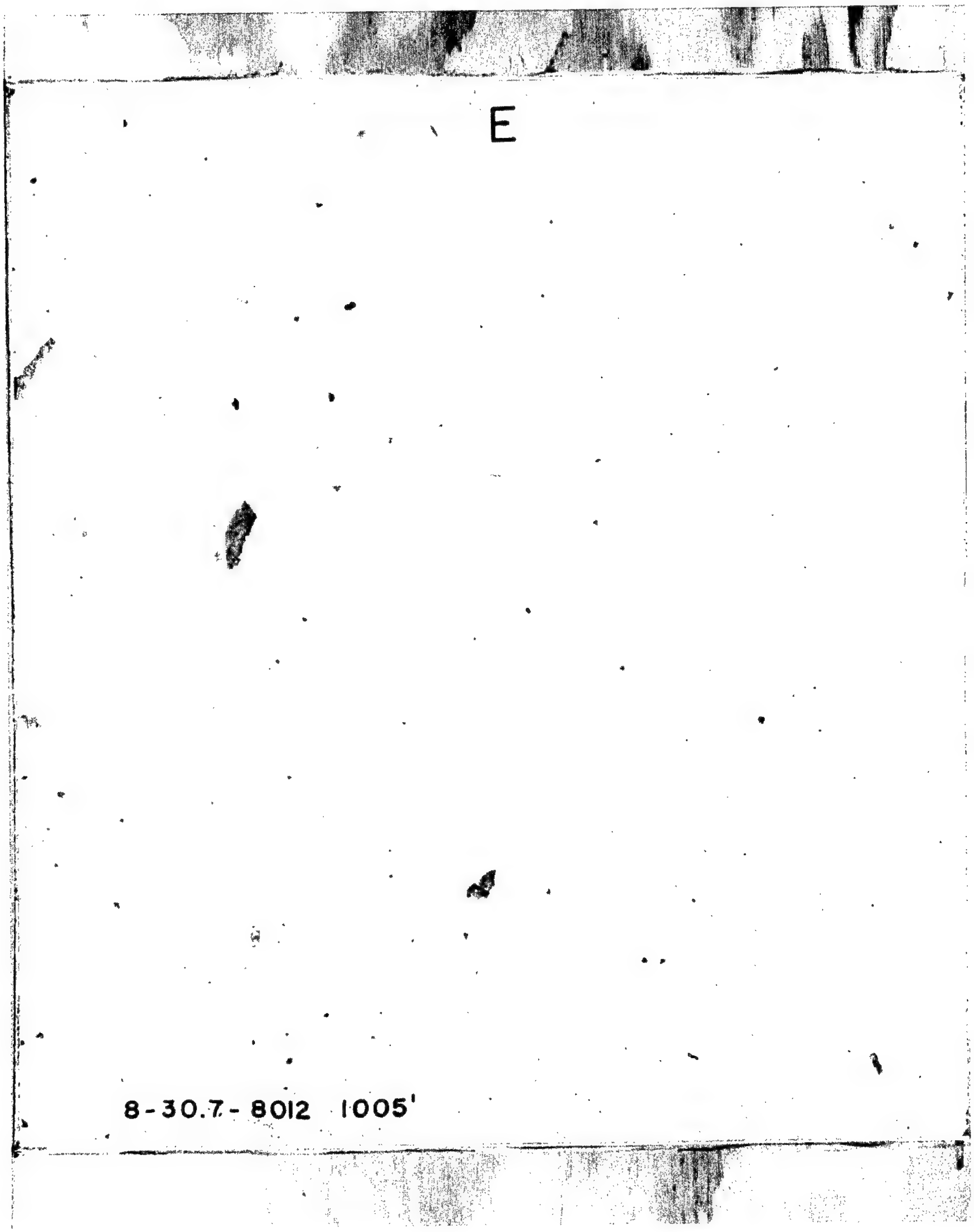


Fig. 3.19—Type B experimental dust collector from circular structure CAb (8-30.7-8012) (Smoky).

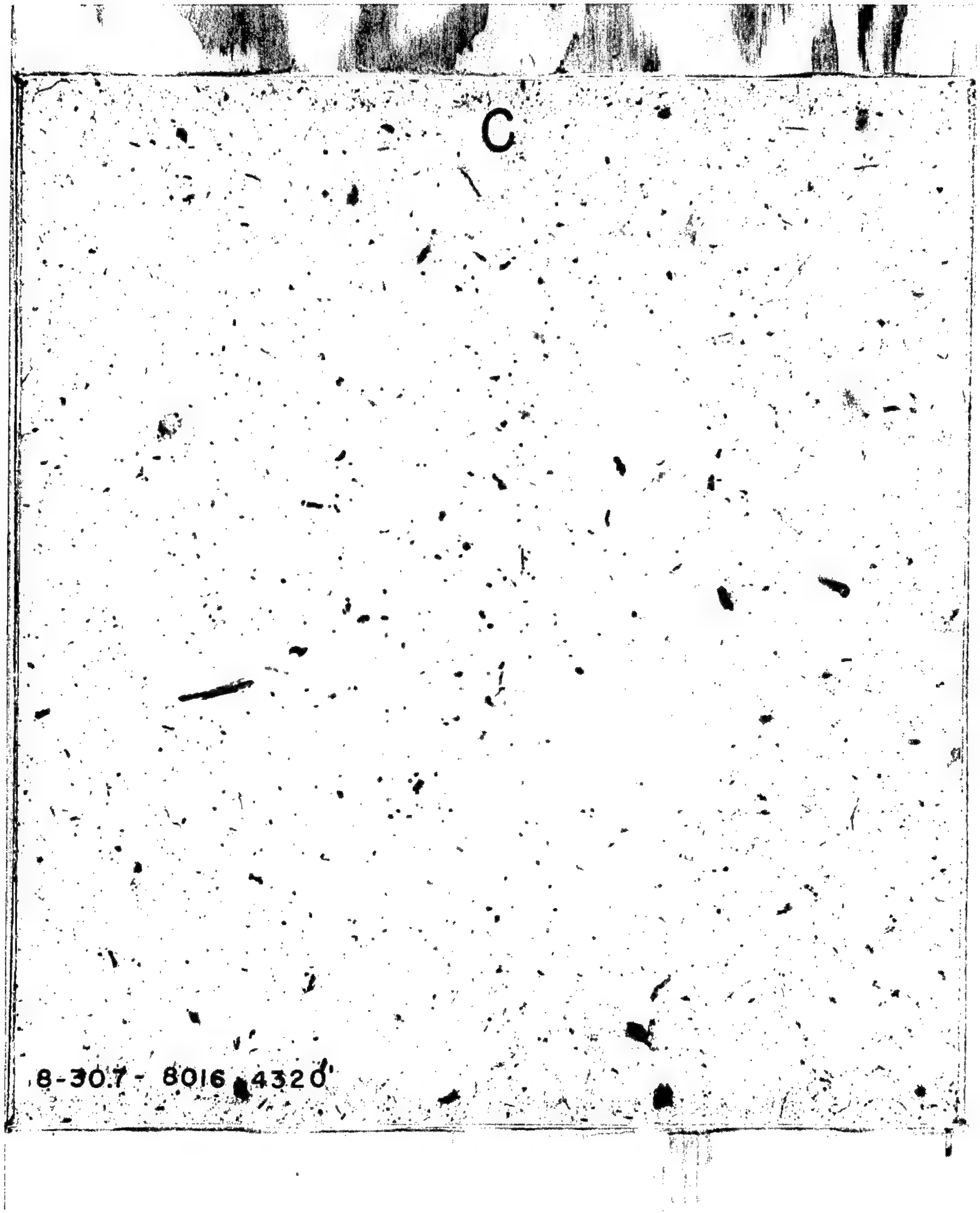


Fig. 3.20—Type B dust collector used as a "dirty" control in rectangular structure RCc (8-30.7-8016) (Smoky).

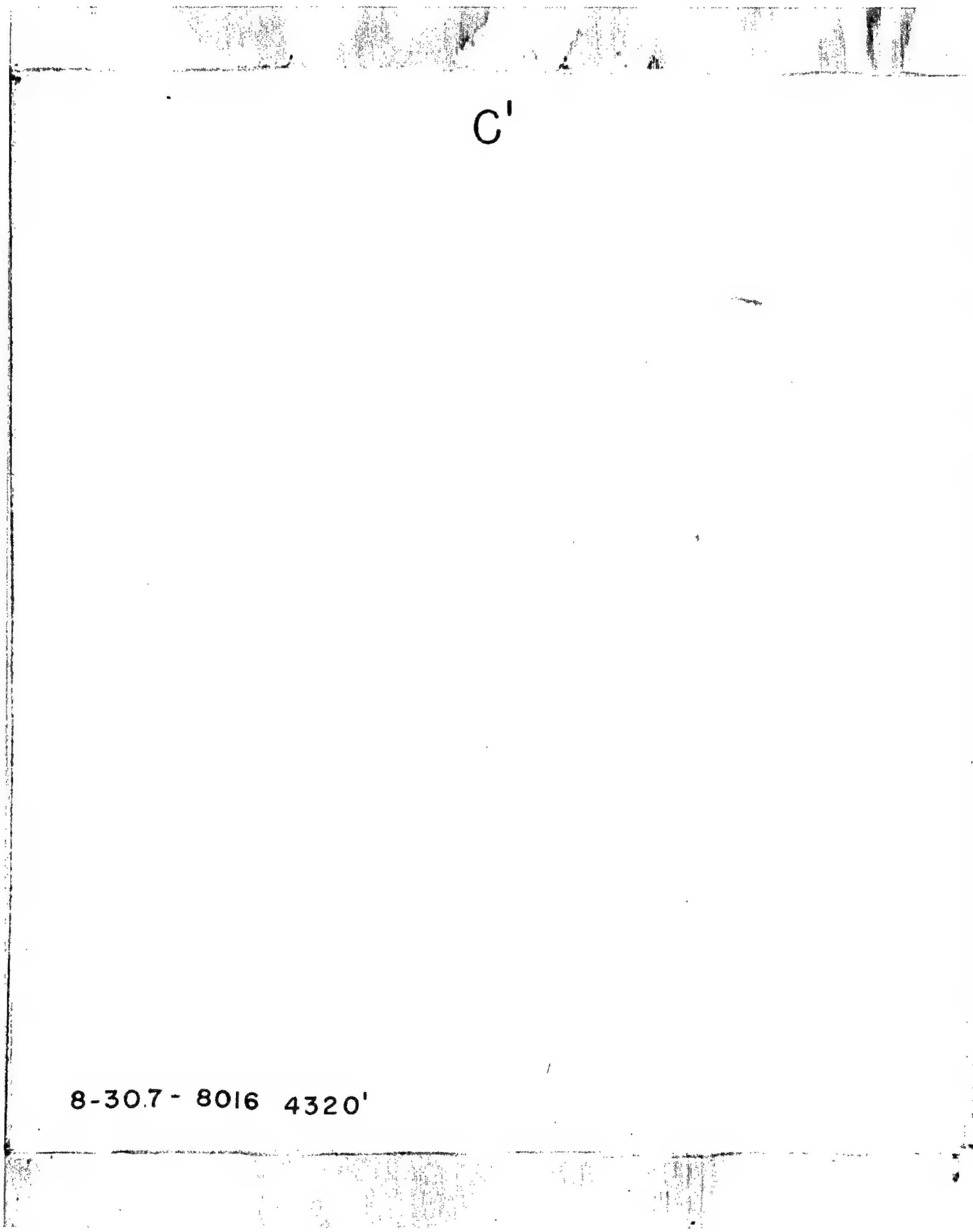


Fig. 3.21—Type B dust collector used as a "clean" control in rectangular structure RCc (8-30.7-8016) (Smoky).

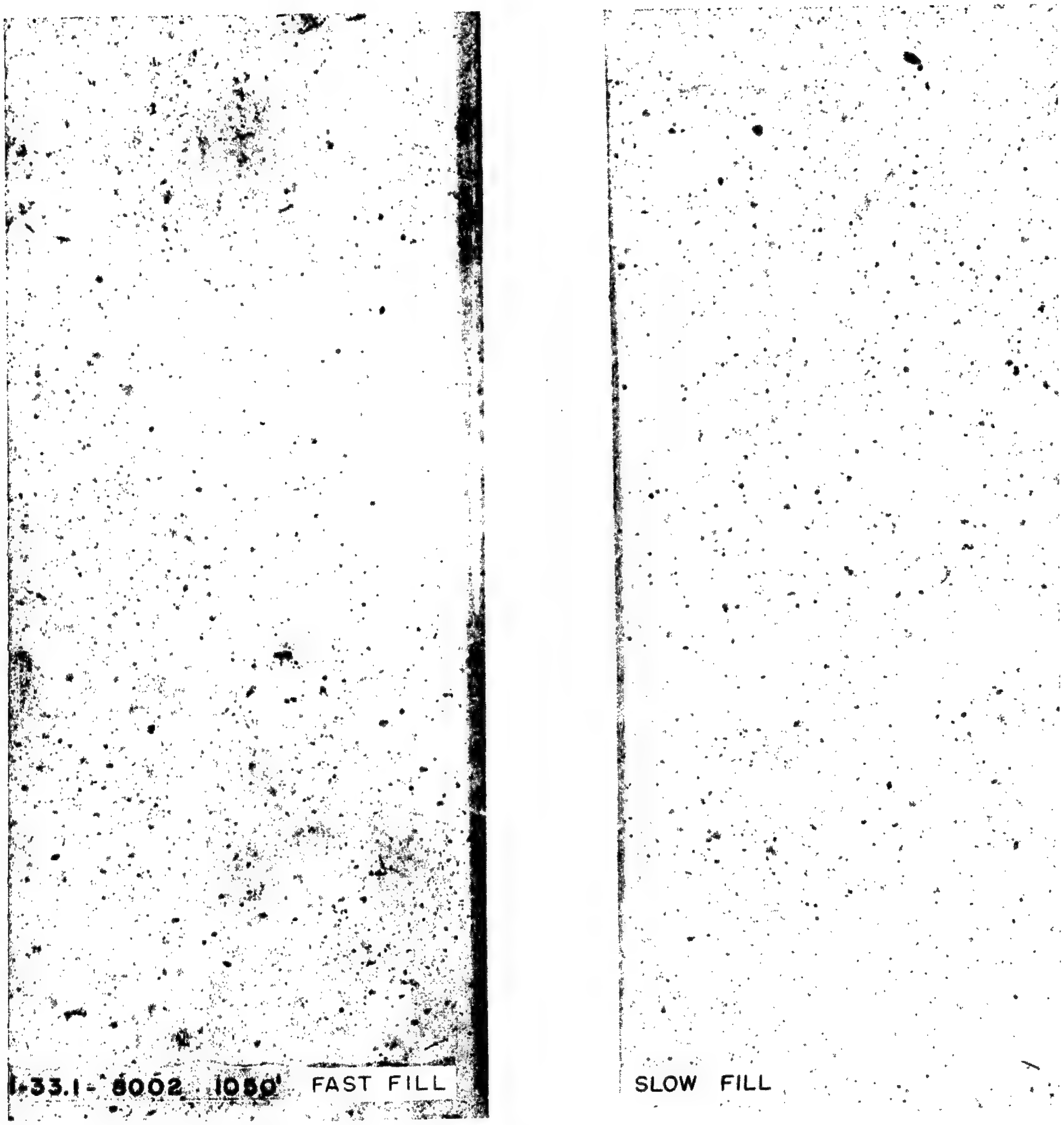


Fig. 3.22—Type B experimental dust collector from the slow- and fast-fill sides of structure 1-33.1-8002 (Galileo).

base laboratory the trays were uncovered and illuminated with ultraviolet light. No fluorescent particles were noted. However, in line with preliminary investigations in the home laboratory, each tray was held over a beaker of hot glycerine. This procedure served to activate the dye. Subsequent illumination of the trays with ultraviolet light revealed small fluorescent particles visible to the naked eye on all collectors. These varied in number from 20 to 50, and somewhat surprisingly there were more particles on trays from the RCb structure located 2430 ft from GZ than on the collectors in the shelters RAd, CAb, and RAa at 1176, 1005, and 840 ft, respectively. It could be that the difference in wall and ceiling thicknesses, about 1 ft for the RCb structure and near 2 ft for the other dye-treated shelters, along with the difference in earth cover, 3 ft for the far and 4 or 5 ft for the near shelters (see Table 2.2), accounts for the variation noted.

Whatever the explanation, the appearance of fluorescent particles on the experimental trays proves that spalling of fine particulates occurs in underground structures exposed to atomic blast. Although microscopic data are not yet at hand, the sparsity of visible dye-treated particles suggests that actual spalling from the walls was minimal and would be of little hazard to personnel.

## 3.3 AIR SAMPLER (TYPE E) COLLECTOR

In the circular structure CAb postshot, a heavy odor of gasoline and exhaust fumes was apparent, the generator was not running, and the air sampler had failed to operate, having been set to begin sampling a few moments before shot time. No doubt, the generator failed from lack of an adequate air supply. These events are worth reporting if for no other reason than to emphasize the danger of placing engine-driven equipment in structures intended for personnel, a fact established by the death from carbon monoxide poisoning of 20 mice placed in the CAb structure (ITR-1507).

## 3.4 FUTURE STUDIES

The data obtained warrant further laboratory analyses using microscopic, photographic, and chemical methods. Tentatively contemplated are microscopic studies to identify as much of the trapped debris as possible and to establish the particle-size distribution of pre- and postshot dust applicable to each structure using the dirt samples collected preshot, the preshot sticky-tray controls, the microscope slides, and all the postshot experimental dust collectors. Chemical methods may be of help in establishing the identity and origin of the postshot dirt, whether from walls and ceiling or from preexisting dirt on the floor. Lastly, the weight of material trapped postshot can be determined by dissolving away the sticky

paper or resin, and an attempt can be made to arrive at a rough estimate of dust concentration existing inside each shelter after the detonations.

Chapter 4

## DISCUSSION

An unanticipated result from the dust studies was the Smoky finding, which make it apparent that dust collectors similar or equivalent to those employed can be useful in future studies of shelters and shelter components for dust leakage. Any structure designed for personnel wherein the designer's intention is to produce a sealed structure or one in which "a functional" seal is desired should be appropriately tested. Dust collectors will prove useful in this regard.

Results with fluorescent material established that spalling of fairly fine material definitely occurred. The occurrence of more spalling in the lighter Smoky structures than in the heavier ones, even though the former were at greater range with less earth cover, suggests that the dye and sticky-tray technique might be useful in structural studies; e.g., what is the difference between a structure which spalls and one that does not? The occurrence of fine spalling material must indicate a type of structural response to loading, the explanation of which might be both interesting and useful. Certainly the occurrence of gross spalling is very carefully assessed by engineering talent, and it seems sensible to suggest that the existence of fine spalling is a refinement in technique of considerable worth, i.e., is fine spalling simply an event which precedes gross spalling? What is the relation between fine spalling and the occurrence of very fine cracks in concrete walls after loading tests? For example, a very careful look at the interior walls, ceiling, and floor of structure RCa (8014), a structure in which fine spalling was comparatively great, is indicated. The finding of tiny cracks would not be unexpected.

Although it is not possible at present to formulate any firm statement concerning the possible hazard to personnel of the postshot dust and debris which existed inside the several shelters, the authors are of the opinion that further analysis of the data obtained will

support the claim that, under the conditions of test, "normal" occupants of the structures would have suffered no serious and immediate harm from dust. The dust and debris, no doubt, would have been annoying to personnel, perhaps definitely irritating and conducive to asthmatic attacks in sensitive individuals, but from the discussions of Desaga[1] and the data of Findeisen,[2] Abramson,[3] and Reif et al.,[4-7] it is unlikely that dust tatooing or significant respiratory deposition of particulate material would have occurred. However, the very fine dust found in some of the Smoky shelters certainly should be carefully assessed as a respiratory hazard.

Lastly, design personnel should keep the dust problem in mind for it no doubt is possible by a few simple techniques to eliminate or minimize the occurrence of dust inside protective structures. Such things as thin metal or plastic liners for concrete shelters, the use of heavy rather elastic paint, the avoidance of grouting and coatings of all kinds which will spall, adequate guarding of ventilation ducts, and air scrubbers all deserve consideration.

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Chapter 5

## SUMMARY

1. The possible occurrence of dust inside underground structures exposed to nuclear blast was investigated.

2. Eighteen underground shelters were used: eight in the Priscilla shot, nine in the Smoky shot, and one in the Galileo shot.

3. The structures ranged from 1360 to 860 and from 4320 to 840 ft from GZ for the Priscilla and Smoky explosions, respectively. The Galileo shelter was located 1050 ft from GZ.

4. All the Priscilla structures were tested with hatches and ventilation ducts closed. The Smoky shelters were closed except that there was no valve in the ventilation duct; instead the ventilation duct was guarded by a sand filter on the intake side. The two compartments in the Galileo shelter were tested with main entry way and escape hatch open, the latter being covered by a plate with multiple perforations (1/4-in. holes).

5. Pre- and postshot dirt was collected using a total of 12 microscope slides, 52 sticky-paper and 4 sticky-resin fallout trays.

6. To establish whether or not postshot dirt arose from particulates kicked from the walls and ceilings by the spalling phenomena, four Smoky structures were treated with a fluorescent-dye solution and four sticky-paper and four sticky-resin collectors were employed for special study.

7. All dust collectors were recovered postshot and inspected. The majority of the sticky-paper tray preparations were photographed using transmitted and reflected light. Reproductions of the photographs are presented.

8. Dust and debris as a consequence of the explosions

definitely settled from the internal atmosphere of the shelters.

9. The occurrence of hard concrete particulates and fluorescent particles on the preparations recovered from the dye-treated structures indicated the existence of spalling phenomena.

10. Finding of many soft particles of concrete mortar in shelters where grouting or patching of defects was accomplished demonstrates the inadvisability of using such construction techniques in blast-protective structures.

11. The mass of the collected material, both microscopic and macroscopic, was in general greater the less the range from GZ.

12. Relatively fine uniform dust in comparatively great amounts was noted on the trays recovered from the forward Smoky structures. It was suggested that this material was blown through the ventilation system into the structures since all doors were closed and survived the blast.

13. Fluorescent particulates were more prevalent in the lighter Smoky structures with lesser earth cover located at greater ranges than was the case for the heavier shelters with greater earth cover located closer to GZ.

14. The possible use of fine spalling as a more sensitive test for structural response than grossly apparent spalling was suggested and discussed, as was the dust collector as a means of evaluating shelters and shelter components for dust leakage.

15. Although it was tentatively suggested that dust as it occurred in the shelters studied would not have been an immediate hazard to personnel, the annoying and irritating effects were mentioned as undesirable, and minimizing or eliminating the occurrence of dust through appropriate design was suggested as an objective of engineering personnel.